

CHAPTER 3

REVIEW OF FORENSIC ANALYSIS AND PROFILING OF ILLICIT HEROIN

3.1 Preliminary

As dangerous drugs have many harmful effects on users as well as the community, their use must thus be controlled by the national government and international organizations. In drug control, forensic science plays a significant role in identifying the dangerous drug and determining the level of the drug in order to show the occurrence of drug abuse. Similarly in other criminal cases, forensic science gathers experts from different disciplines to provide professional opinions on a single issue before a judgment is made in court. But, how do they form unbiased opinions? Are their opinions scientific? As for drug abuse and trafficking, must there be a series of laboratory analysis? To this end, this chapter seeks to review the basic concepts of forensic science and its application in drug analysis and drug profiling. Special emphasis will be given to the past research done on illicit heroin.

3.2 Overview of the Forensic Science

Forensic science (or forensics) is a multidisciplinary field that adopts a combination of scientific tests in criminal cases. This state-of-the-art science requires diverse knowledge from different fields to perform empirical studies and interpretation on a single case before a conclusion is drawn and presented in a court of law. For example, a hit-and-run case will involve the knowledge of physics to study skid marks, the chemistry for paint analysis, molecular biology for deoxyribonucleic acid (DNA) analysis as well as automobile experts to identify the year and model of the vehicle

based on the tread marks. Other related expertise may also be required to re-construct the incident. Hence, forensics is a specific field that employs scientific knowledge throughout the course of finding and testing the exhibit/evidence seized from the scene of the crime. In line with the aim of this study, analytical chemistry is cited as a specific science throughout this discussion since it plays a significant role in forensic drug control.

3.2.1 Foundation of Forensic Sciences

As forensic science is the application of sciences to medico-legal issues, the primary aim of a forensic analysis in a broad sense is to provide unbiased scientific findings to show whether a crime has been committed; subsequently to establish links between the perpetrator and the samples recovered from the scene of the crime and/or the victim. Therefore, scientific findings are the intermediary between facts and exhibits (Figure 3.1). Forensics interprets the scientific findings to provide intangible truth (e.g. associating evidence with a person) derived from the tangible objects (e.g. drug seizures and fingerprints) seized from the crime scene or the person. So, scientific testing is a central part in the entire investigation. Many of these tests are performed based on the principle of analytical chemistry. In almost all routine forensic analyses, the role of analytical chemistry is to find target compounds and/or determine the levels of the compounds in a given sample. These target compounds form the basis of the evidence that a forensic scientist should look for, while the whole drug entity is merely the exhibit which may or may not contain the evidence.

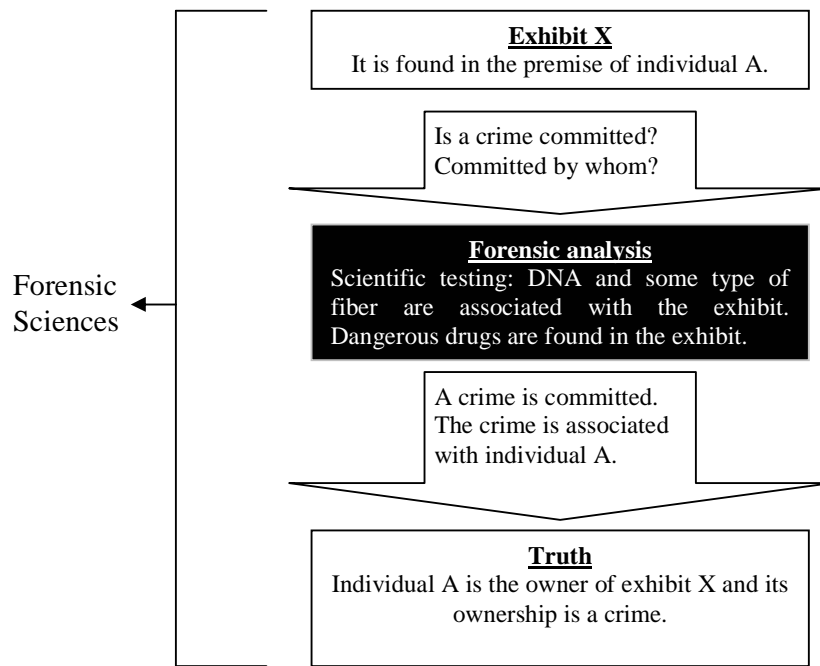


Figure 3.1: A general scheme of forensic science

In most cases, the evidence is present in trace amounts and can be easily overlooked. However, all forensic practitioners theorize that regardless of how thorough the criminal cleans the crime scene, clues associated with the crime may remain at the scene for the forensic investigator to find and for the forensic scientist to decode (Murdico, 2004). As a result, more effort is dedicated to the investigation of the crime scene as there may be inadvertently hidden clues. The investigator cherishes the idea that everyone will lie except the trace evidence. Therefore, they strive to recover as much as possible the physical clues from the crime scene, expecting that the complete clues will finally reveal the details of the crime. Due to the highly complex nature of the recovered material, many scientific methods have been invented to locate more useful evidence such as dangerous drugs, fibers, blood, DNA, etc in a gross exhibit (e.g. a powder, textile, liquid, etc) before a crime is confirmed to have taken place. These clues are mute, hidden and unprejudiced. At the initial stage, a scientific technique such as forensic polilight may be used to locate hidden blood splatters in a murder case. In drug

investigation, an X-ray detector is frequently employed to locate possible drug traces at the crime scene. But the final confirmation can only be obtained with separation science through instrumental analysis. Separation science enables the segregation of a target compound from a large pool of extraneous compounds. As for the recovered blood stains, capillary electrophoresis will be of great utility to separate and profile the DNA extracted from the blood sample in order to determine the identity of the owner. Similarly, chromatographic techniques are frequently used in drug analysis to isolate target poisons and dangerous drugs from the seized sample. More meaningful findings can be obtained when samples of known sources called standards or specimens are provided for comparison. In so doing, the recovered sample from an unknown origin can be compared against the standard so as to determine if they share the common set of characteristics. The conclusion that both samples contain the same type of compound or to have come from the same source is finally accepted only when the predetermined characteristics are found to be highly matched.

Forensic science operates on two basic principles (which include six dimensions: transfer, identification, individualization, association, reconstruction and divisibility), all of which provide the basis for forensic investigation (Kirk, 1963; Inman & Rudin, 2002). Briefly, these principles are described as follows:

1. **Locard's Principle of Transfer** with its 'every contact leaves a trace' points out that the criminal will exchange physical traces between himself/herself and the crime scene, the victim(s) and all other relevant objects when they come into contact. This principle forms an essential basis for two other concepts in forensic science, namely association and reconstruction. Association of physical evidence with a common source is based on the likelihood of transfer while reconstruction is the ordering of association in space and time.

2. **Kirk's Principle of Individualization** provides scientific grounds for making comparisons between two objects since nothing is identical in this universe. As each entity is unique in an absolute term, forensic science could only establish similarity to predict if two items are from a common source in a relative term. Two other concepts have also emerged, namely identification and individualization. The former aims to put items sharing common characteristics in a class whereas the latter further distinguishes items within the class. Later, a relatively new concept, divisibility of matter, has also been added to the dimension of individualization. Due to the temporal instability, this new concept allows some degree of disagreement in the characteristics of two items coming from the same source.

In line with the two principles, forensic practitioners accept that trace evidence inevitably reside in/on the object with which the perpetrator has come into contact. Science is a valid tool to identify and individualize these traces because no two objects are similar unless they come from the common source. When the traces and those seized from the perpetrator are found to be of a common source, the perpetrator can then be associated with the crime and the sequence of events can also be established.

In the present context, the scope of forensic science is ever widening due to the emergence of more and more new things in the modern world. For instance, analysis of technological devices involved in a cyber crime has become a part of forensics as computers are widely adopted in today's activities although this field did not exist decades ago. By employing more advanced analytical and statistical tools, forensic drug profiling has also been incorporated in the scope of forensics to find hidden truth about drug trafficking activities.

3.2.2 Drug Analysis

In drug analysis, traces refer to the controlled substances concealed in a bulk mass. One kilogram of active drug added to one tonne of cutting agents eventually becomes a trace. For incrimination purposes, routine laboratory analysis is aimed at revealing the presence of the dangerous drug of interest rather than a full list of compounds present in the sample. For instance, when a kilogram of a white powder is suspected to contain heroin, the drug chemist will only verify the presence of heroin by shifting all analytical work to the determination of this drug rather than anything else. For quantification, its level is determined using a reference standard. The purity level of the target drug will indicate the severity of the crime which in turn helps the judge in court to make decisions on the penalty. In other cases, the dangerous drug is no longer the trace evidence when it forms the significant portion of the bulk mass. This sample is as such because it has not been cut and to some extent, is indicative of the earlier stage in the distribution chain. This can be envisaged when the above-mentioned one kilogram of drug is adulterated with one gram of any material. Where routine analysis is concerned, the narcotics scientist tends to use chromatographic techniques and mass spectrometry to identify and quantify the target drug respectively. For prosecution, the true quantity of the drug measured against a chemical standard is reported in absolute term. In contrast, for non-routine drug profiling the instrumental findings can be reported in a relative term. Besides, both the target and non-target compounds defined in the routine analysis are however the targets in drug profiling. Therefore, drug profiling is more tedious than routine drug analysis as the former has a long list of compounds to be determined as compared to the latter which usually focuses on one or two target compounds.

In drug analysis, several drug items have been defined by UNODC (2009b). This provides harmonized definitions to minimize confusion arising from the usage by different laboratories.

Seizure: The entire quantity of items seized. This may consist of a single population or a number of populations.

Population: The collection of items under discussion. A population may be real or hypothetical; finite or infinite; homogeneous or heterogeneous.

Package: A container for a single unit, a number of units or a number of other sub-packages.

Unit: A single individual element of a population (e.g. a single tablet or a single package containing powder).

Sample: A unit or a number of units selected from a population.

In the forensic framework, any of the above items may be encountered. These items must ultimately be processed into a laboratory sample for analysis. The laboratory sample must be a random and homogeneous product that is representative of the grouped items. UNODC (2009b) recommends the drug chemist to use a ‘black-box’ sampling method to obtain a representative sample. This is done by randomly selecting a number of items from a black box containing samples of similar appearance. As illicit drugs are usually submitted in packages, sampling can also be conveniently done based on the number of packages, and these specific procedures are detailed in the manual issued by UNODC (1998).

Different laboratories may have their specific schemes for drug analysis. The adaptation is usually done to suit the local legal requirements. For example, certain judicial system does not require the quantitative analysis of the dangerous drug and

hence this step is eradicated. Figure 3.2 illustrates a general scheme of drug analysis commonly adopted by narcotics laboratories. This scheme is modified from that of Cole (2003).

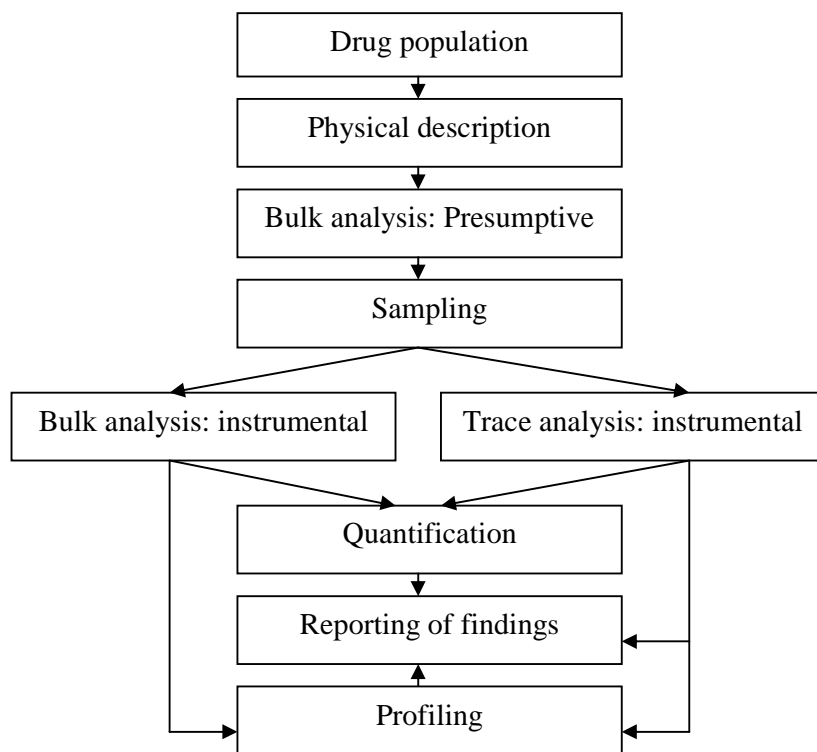


Figure 3.2: General steps for drug analysis

As a general procedure, only the contents in packages that are seized from the same location and share the common physical appearance can be mixed. Besides, they are mixed unless presumptive tests prove positive for the target compound in each package, otherwise only the packages showing positive reactions should be mixed. The mixture must be homogenized before sampling is performed. Sampling is a means to obtain a small portion of the bulk homogenized sample. It provides an economical means to reduce the number or the amount of samples for analysis without jeopardizing the accuracy and validity. The sampled item will be subjected to routine analysis which involves the determination of the compound of interest using instrumental analysis,

followed by quantification if applicable. Other laboratories may perform extra analytical work to screen the general profile of the drug sample using an eclectic approach combining classical and instrumental analyses as well as statistical approach. The un-routine drug profiling serves to derive intelligence knowledge from the samples for comparison, enabling the forensic practitioner to understand, predict and control trafficking activities in the local and international contexts.

The following sections will highlight the analytical aspects of illicit heroin. As the analysis and profiling of illicit heroin differ in their goals and nature of work, they are thus discussed separately.

3.3 Analysis of Illicit Heroin

Analysis of illicit heroin denotes the type of analysis that only determines whether a sample contains diamorphine so that prosecution can be carried out. In the course of determining diamorphine, other opium-based alkaloids may sometimes be analyzed. This may overlap the work of heroin profiling but differences in terms of analytical work and goals do exist. Routine analysis aims to prove the presence of crime related compounds solely for prosecution purposes. As the Malaysian legislative system proscribes the use of diamorphine, morphine, codeine and MAM, all of which co-exist in the illicit heroin, so the drug chemist is inevitably concerned with more than just diamorphine in the routine analysis. A routine procedure in the analysis of illicit heroin encompasses visual examination, physical analysis, chemical analysis and instrumental analysis.

3.3.1 Visual Examination and Physical Analysis

Conventionally, visual examination and physical analysis is largely focused on tablets and capsules as these smallest entities are rich in measurable details. In contrast,

little emphasis is given to the mixed colored and irregular forms of illicit heroin because humans are usually comfortable with the constant color and fixed diameter of tablet. For powdered substances, descriptions on color, texture, weight, smell and other relevant visual appearance are often underestimated. This is probably due to the fact that these descriptions are too subjective and frequently lend most incompetent analysts to systematic errors. In addition, these characteristics are of limited evidential value for prosecution in court. Despite the controversy, this aspect however merits a preliminary step for sampling planning (UNODC, 1998).

As a matter of fact, the roadmap of analysis is primarily based on the initial findings obtained from visual examination. Taking ecstasy pills as an example, the logo of 'WY' is useful to give the first indication to the chemist to analyze for methamphetamine. Similarly, visual inspection on the general appearance of an illicit heroin sample also provides a useful hint to the next testing scheme. Based on prior knowledge, whitish fine powders are indicative of heroin and ketamine. Crystalline samples can definitely rule out the possibility of heroin. Samples in a rough granular form would usually point to heroin. With these preliminary findings, unnecessary work can be minimized. Besides, the purity level judged from the physical characteristics associated with the sample could also be predicted. For example, samples in medium-brown, hard chunks with vinegar-like odor suggest purity 40 – 60% heroin, while colored hard granular materials suggest 25 – 45% heroin hydrochloride (UNODC, 2003). This observation in turn provides a guide to the chemist to prepare a suitable calibration range for quantification. Certainly, these subjective observations are not valid in court. They could only serve as a preliminary idea for planning the laboratory analysis. In the routine analysis, the Malaysian laboratory will usually record the color, smell and net weight of the illicit heroin. The chemist will also photocopy the drug item

to preserve its original condition. These observations are only used as a reference for future court testing.

A relatively tedious approach described by Holt (1996) for the analysis of illicit heroin particulates is rarely practiced in routine analysis. In the study, the researcher demonstrated the use of heptane as a non-solvent to suspend illicit heroin for particle size analysis with five sieves of different mesh sizes. Subsequently, the percentage by weight of the samples from each fraction was determined. With this approach, samples of limited capabilities such as heroin powders can be enabled to give more physical data. Until recently, literature describing analytical work on visual and physical aspects of illicit heroin is extremely limited. In fact, part of the reason for poor devotion to this aspect is largely due to the lack of interest of the local judicial system in the physical findings.

3.3.2 Chemical Analysis and Instrumental Analysis

As chemical analysis and instrumental analysis are costly, unworthy waste must thus be avoided. Prior to analysis, the drug of interest must be predefined by the chemist so as to minimize unnecessary analytical cost incurred by redundant analysis. In a common practice, an arbitrary decision is made initially based on the visual examination carried out at the early stage. For example, an analytical scheme for illicit heroin is decided for a mass of white granules when its appearance is found to be highly associated with genuine heroin samples. This decision is either affirmed or dismissed with the aid of presumptive tests that give a rough inference as to whether the drug of interest is tentatively present. In fact, this presumptive test is specifically designed for screening purposes. This screening step helps narrow down the scope of analysis which in turn provides a clear direction for the chemist to proceed with confirmatory tests.

To acquire a preliminary insight about the substance being analyzed, color tests (or spot tests) are common in narcotic drug analysis. For illicit heroin, the Marquis Test, Mecke Test and Frodhe Test are commonly used. In these tests, color changes upon the reaction between the reagents and the target compounds are the positive indication for the presence of diamorphine or opium-based alkaloids. According to Table 3.1, most reagents in the tests tend to give a purple coloration for positive response. Among the three tests, Marquis Test is most preferably employed by many narcotics laboratories as it can also be used to screen for methamphetamine and ketamine which respectively give an orange coloration and bubbling foams when tested positive.

Table 3.1: Color changes upon reacting with various opium-based alkaloids in Marquis, Mecke and Frohde tests

Alkaloid	Color test result		
	Marquis	Mecke	Frohde
Heroin	Purple violet	Dark green	Purple becoming grey/purple
Morphine	Purple violet	Dark green	Purple becoming grey/purple
Codeine	Purple violet	Green/Blue	Blue/Green
6-MAM	Purple violet	Dark green	Yellow/Green
Acetylcodeine	Purple violet	Dark green	Purple becoming paler
Papaverine	No color	Dark blue	Light green
Noscapine	Bright yellow	Green/Blue	Cherry red

(Source: UNODC, 1998)

Although the color test is rapid and economic, the selectivity and sensitivity are relatively poor. The fact is that presumptive test reagents are not specific to one individual opiate drug but rather to the class of opiates; further tests are required to

determine which of the opiates are actually present in the tested item. In a complex matrix, this preliminary test is prone to false positive and false negative observations. False negatives are attributed to the poor sensitivity of the test since the reagents are easily impeded by the presence of other interfering adulterants. As a result, a larger amount of the drug substance may be required for a color test to show a positive response if the target drug is truly present. In view of these shortcomings, more reliable analytical techniques are required. With chromatographic techniques in particular, the major opiate (heroin) together with other opiates (e.g. morphine, MAM, codeine, etc) can be identified concomitantly because separation and detection can take place simultaneously.

In separation science, many old techniques for chemical analysis have been improved to cater to contemporary needs. For instance, gas chromatography (GC) which was developed in the 1960s is an obvious improved technique from thin layer chromatography (TLC) which was invented in the 1950s although the nature of separation is quite different. These classical and advanced techniques are still recommended by UNODC (1998) for the analysis of opium and illicit heroin.

Planar chromatography comprising paper chromatography (PC) and TLC is the most cost effective and simplest type of separation technique affordable in any laboratories around the world. Briefly, this technique utilizes a mixture of solvents to isolate various compounds on a flat platform based on differential affinities of analytes toward the stationary and mobile phases. Both PC and TLC are commonly used for qualitative analysis since they are amenable to a wide range of compounds and visualization techniques (UNODC, 1998). In fact, their analytical capability can also be enhanced with the use of a spectrophotometer to offer quantitative analysis. This was demonstrated by Asahina and Ono (1956) who employed PC and spectrophotometry to isolate and quantify morphine and the related alkaloids from the opium poppies. Instead

of PC, TLC is highly recommended for drug screening. The TLC systems are aplenty for illicit heroin analysis and all of them are sufficiently good for the resolution of most of the major opiates and adulterants found in the illicit heroin. However, it is not ideal for the isolation of 3-MAM and 6-MAM. To rectify this problem, Huizer (1983a) introduced a pre-coated silica gel plate which can enhance the isolation of the two compounds in the illicit heroin. However, this must be used synergistically with the potassium iodoplatinate spray and heating through which the lower level of 3-MAM can fluoresce under the ultraviolet (UV) light at 366 nm (Huizer, 1983a). Later, Rajananda, Nair and Navaratnam (1985) have also identified a minimum of 38 TLC solvent systems for opiate analysis, all of which being relatively thrifty techniques in drug testing. They also concluded that chloroform:n-hexane:triethylamine in the ratio of 9:9:4 was the best solvent system for the identification of diamorphine and many other alkaloids in a complex mixture. UNODC (1998) on the other hand recommended toluene:acetone:ethanol:concentrated ammonia (45:45:7:3), ethyl acetate:methanol:concentrated ammonia (85:10:5) and methanol:concentrated ammonia (100:1.5) as three alternative solvent systems for general screening of illicit heroin. Apparently, TLC is more reliable than color tests as the specificity is enhanced by solute separation which can greatly minimize the interference associated with extraneous compounds. In addition, TLC proved more sensitive than color tests and PC. According to Cole (2003), an illicit sample prepared at 1 – 10 mg/mL is sufficient for visualization of the majority of compounds found in the sample.

An improved version of TLC termed high-performance thin layer chromatography (HPTLC) was slowly gaining attention from the drug chemist in the 1980s due to its rapid analysis time, higher throughput and suitability for quantification. The reproducibility of HPTLC coupled to a photodensitometer in heroin analysis was experimented by Casa and Martone (1986). They found that HPTLC was a rapid and

accurate technique for qualitative and quantitative analysis of illicit heroin and was comparable to gas liquid chromatography (GLC) technique. Despite its usefulness in narcotic analysis, TLC is however hardly acceptable as a confirmatory test. More sensitive and selective instrumental techniques have been recommended to achieve this objective.

In the late 1970s, immunoassay operating on the antibody-antigen interaction replaced TLC. Since the antibody chosen as the reagent for reaction is specific to the antigen analyte, this technique is therefore relatively sensitive and selective than planar chromatography. During its emergence, this technique was a method of choice for high throughput analysis as immunoassay offers far more sample wells than TLC for sample loading. It also saves more analytical cost when a large batch of samples can be analyzed in a single run. Later, this technique was found to be unreliable for the detection of diamorphine in highly complex samples because it lacks the specificity to detect individual alkaloids. In this regard, Jankanish (1993) also asserted that immunoassay technique has its drawbacks in that codeine could give a false positive reaction for morphine.

GC using a gaseous mobile phase not only provides a better reproducibility but also minimizes the need for large volumes of solvents for separation as compared to planar chromatography. In addition, different stationary phases ranging from polar to non-polar films of chemicals coated on the columns further diversify the possibilities in chemical separation. Besides, better selectivity and sensitivity can be achieved when different detectors can be optionally chosen for a GC based on the properties of the target compounds. Among others, mass spectrometry (MS) is the most sought-after analytical detection technique for drug analysis as it provides confirmatory results through library searching in addition to its rapid analysis time, less sample preparation, high selectivity and sensitivity when it is hyphenated with GC. In addition,

identification and quantification of heroin at microgram level is possible with GC-MS (Nakamura & Noguchi, 1972). However, the co-elution issue that leads to unreliable quantitative results offered by GC-MS rendered this technique controversial. Following this issue, Chow (1981) used a selected ion monitoring (SIM) mode as a more reliable alternative to quantify the contents of heroin and deuterium-labeled heroin. The study concluded that this technique functioned satisfactorily well and could be employed for quantitative studies. For accurate quantification, a flame ionization detector (FID) that is capable of summing up the number of carbon atoms in the eluent is preferably employed for organic analysis. When GC-FID is used for routine heroin analysis, UNODC (1998) recommends that reliable quantitative readings must be suitably calculated from the chemical standards normalized to an internal standard. It is also recommended that n-alkane, amitriptyline or benzopinacolone should be used as the internal standard for this purpose. The method can adopt either a packed column, megabore or narrow bore capillary column for separation. More importantly, the GC must be well-maintained on a regular basis in order to eliminate decomposition associated with the high operating temperature and the presence of contaminants around the injector port.

An alternative to GC is high performance liquid chromatography (HPLC) that utilizes a liquid solvent as a mobile phase and a significantly short column for separation. Similar to MS, a unique spectral fingerprint can be obtained with an ultraviolet diode array detector (UV-DAD) when it is coupled to HPLC. Lurie and Carr (1986) used HPLC-DAD with three wavelengths at 210 nm, 228 nm and 240 nm to analyze and quantify heroin and its alkaloids. The method showed good peak separation despite the presence of commonly encountered adulterants. Besides, co-elution can be detected by the deviations observed in the spectra recorded at the selected wavelengths. This method however requires a longer analysis time, lasting up to one hour.

At present, instrumental chromatography remains the technique of choice in all narcotic analyses due to the excellent separation power it can offer for complex matrices. As a result, other techniques such as Fourier transform infrared spectrophotometry (FTIR) would not be of much utility since it is only best suited for pure samples. To some extent, this less prioritized technique may also be helpful. Ravreby (1987) was able to identify and quantify the diamorphine levels in cut samples using FTIR. Through spectral subtraction, the interfered absorption bands can be corrected to obviate the cutting effects. In this study, the researcher demonstrated that significant signals representing heroin hydrochloride at $\lambda = 1763\text{ cm}^{-1}$ and 1736 cm^{-1} were inevitably interfered by adulterants, but the correction of these signals to some extent proved useful for quantitative analysis. When FTIR is employed for heroin analysis, UNODC (1998) also emphasizes other possible problems with the use of potassium bromide (KBr) in which halide exchange with hydrochloride salts during disc preparation could occur from excessive pressing. For qualitative analysis of illicit heroin in a relatively pure form, FTIR is the most rapid way to obtain a unique fingerprint spectrum compared to other instrumental analyses. Due to the difficulties to predict the purity level of the drug as well as the laborious disc preparation procedure, less interest is therefore dedicated to FTIR. Nevertheless, diffuse reflectance near-infrared spectroscopy (DR-NIR) was also promoted by Moros, Galipienso, Vilches, Garrigues and Guardia (2008). This technique requires little sample preparation and offers a nondestructive nature of analysis. In Malaysia, the chemist may also use attenuated total reflectance-Fourier transform infrared spectroscopy (ATR-FTIR) as a screening step to determine the major adulterant in the illicit sample.

Another innovative technique combining electrophoresis and chromatography called micellar electrokinetic capillary chromatography (MECC) was validated by Walker, Krueger, Lurie, Marché and Newby (1994) for the quantification of heroin. In

their method, the long chromatographic run time was greatly reduced to less than 5 min when a low concentration of sodium dodecyl sulfate with a low volume of the stationary phase and a short length of the capillary were employed. One can stop the analysis after the peak of interest has eluted and to start the next analysis within 2 min. Later, MECC with short-end injection emerged to separate diamorphine from other adulterants in less than 2 min and quantitative determination can be achieved in a much shorter time (Anastos, Lewis, Barnett, Pearson, & Kirkbride, 2005a). However, since MECC is not available in every narcotics laboratory, it is therefore less popular for routine analysis.

The above cited literature is only part of the works recorded in the publication. In fact, many of the techniques have been modified by the local enforcement laboratories to suit their analysis demands.

3.4. The Basis of Drug Profiling

There is hardly an entity sharing an identical set of characteristics with another entity. Even identical twins may show phenotypic variations in their fingerprints, tastes, lifestyles, preferences, etc. In this respect, each physical object is characterized as a unique entity. Two similar objects may appear indistinguishable but its distinction remains somewhat hidden to be studied. A profile is an ideal term to illustrate the unique identity of a person or an object. In a broad sense, a profile is always accompanied by a description of the physical and/or chemical characteristics. For example, the soil profiles of two geographically different regions are revealed by studying the color, texture, wetness, soil type and metal composition of every layer of the lands which collectively give illustrations to the two different lands.

In forensic investigation, the fingerprint and DNA are two highly distinct types of profiles that help distinguish between individuals. This profiling is routinely done because the profiles can be used to identify and individualize a person responsible for a

particular criminal event. Certain profiling work is not routinely done as it does not confer evidential value for prosecution when compared to that of the fingerprint and DNA. This extra effort, if done, only aims to keep the information of a particular piece of crime related evidence such as drugs, criminal personalities, etc in a database so that future tracking can be easily executed for forensic intelligence. Profiling emphasizes the uniqueness of an individual entity. In routine drug analysis, uniqueness refers to a particular object being different from another or being the same with an object showing the same unique result. Hence two objects originating from a common source will show a similar profile which is only unique to the source. In this respect, the term 'unique' is used to describe exclusiveness on a macro scale. For example, a substance has the unique characteristics similar to those of diamorphine rather than methamphetamine. On a micro scale, uniqueness in drug profiling is used to further distinguish between samples of the same type (e.g. brown heroin seized at two different times) but with different histories (e.g. origin, manufacturing process, etc). This can be achieved qualitatively based on the presence or absence of certain compounds. More effective approaches usually employ quantitative comparison since two samples from different sources will exhibit measurable inter-batch variation. In terms of similarity, the concept of divisibility of matter proposed by Inman and Rudin (2002) allows some degree of dissimilarity between entities coming from the same source. This concept is further considered by drug profiling, allowing samples having similar histories to show some degree of discrepancies in their characteristics. This allowance is expressed as intra-batch variation in drug analysis. For comparison, the drug profiles are first obtained to the level at which intra-batch variation can still be observed. Subsequently, these profiles will be statistically treated to minimize the intra-batch variation to establish the sameness between the samples with the same histories, and at the same time to maintain

or maximize the inter-batch variation to establish distinction of the samples with different histories (Moros *et al.*, 2008).

Drug profiles are established using physical and chemical characteristics obtained from the sample level to molecular level. Two types of drug profiling are distinguished as follows (UNODC, 2005; Fraser & Williams, 2009):

Characterization: Various drug samples are described and classified according to class characteristics based on which samples from the same production line can be linked. In forensic drug analysis, the class characteristics on a macro scale are mostly derived from visual and physical examination of a drug substance such as smell, color, shape of the pill, texture of the powder, etc in more or less a standardized form. The findings give a very broad definition to the sample. The profile is also too general and usually represents the group to which it belongs to rather than a unique individual sample because the class characteristics are standard for a batch of drug entities and the features are intended during processing. On a micro scale, the class characteristics derived from chemical analysis focus on the qualitative and quantitative studies of the major components present in the sample. These major components include active ingredients, adulterants, cutting agents and significant impurities. To some extent, these characteristics are sufficient to provide a unique profile for a drug entity. Also, these characteristics result in inter-batch variation that is useful for grouping.

Samples in a group sharing common class characteristics may seem similar at the initial stage. In order to further assign the samples to more specific groups, more highly individual characteristics must be investigated by impurity studies through which

components in trace amounts are profiled. Not surprisingly, forensic profiling may sometimes be defined as ‘the exploitation of traces’ by Rannenberg, Royer and Deuker (2009, p. 334) since the traces are the most informative clues.

Impurity profiling: Many traces or impurities present in the drug sample will collectively serve as a signature for the sample. These impurities are very distinctive and are collected during processing. They are potential sources for forensic intelligence because their uniqueness can further maximize inter-batch variation for sample discrimination. According to Kirk’s principle, individual characteristics enable the fragmented parts of a common source to coincide. The concept of divisibility however emphasizes that a very comprehensive trace profile would also separate a single sample from its batch although they may have originated from the same source. It is because each sample ‘lives its own life’ as an individual entity with its very own history. Many final street samples could be from the same source, adulterated with the same diluents by the same person in the same environment. Minor variations will occur when these samples are subjected to a variety of uncontrollable factors such as contamination (intra-batch variation). In this case, one sample may be placed in a contaminated packet while another may be exposed to heat, and these conditions could result in two slightly different profiles. Therefore, impurity profiling strives to further maximize inter-batch variation while keeping the intra-batch variation to a minimum for meaningful grouping.

Comprehensive profiling will eventually offer a highly distinctive profile after the sample is exhaustively characterized and profiled. Drug profiles can be used in two different frameworks depending on whether they are for evidential or intelligence

purposes. Figure 3.3 explicates that the routine drug analysis would use the drug profiles to identify and then individualize the samples, differentiating them with unique identities. When the profiles are used for intelligence purposes, the investigation becomes a three-tier process. It starts from identification to individualization and then proceeds to identification again. According to Figure 3.4, the drug samples are separated based on preliminary findings (e.g. physical characteristics, location of seizure, purity level, etc) in order to group similar samples in general groups. This is often referred to as the screening step. For example, the substances in question are first characterized to distinguish the type such as brown heroin and pink heroin which routine analysis often concludes them as two different entities. This decision in drug intelligence however is only made after detailed findings are investigated. With the new chemical details obtained through profiling, these samples showing agreement in the details will coalesce in new common groups while those tentatively grouped to be similar can be reassigned to more appropriate groups. The details are the actual identity of the final group. In essence, the variations in these details will enable ultimate grouping on such a basis that inter-batch variations must be greater than intra-batch variations (Fraser & Williams, 2009).

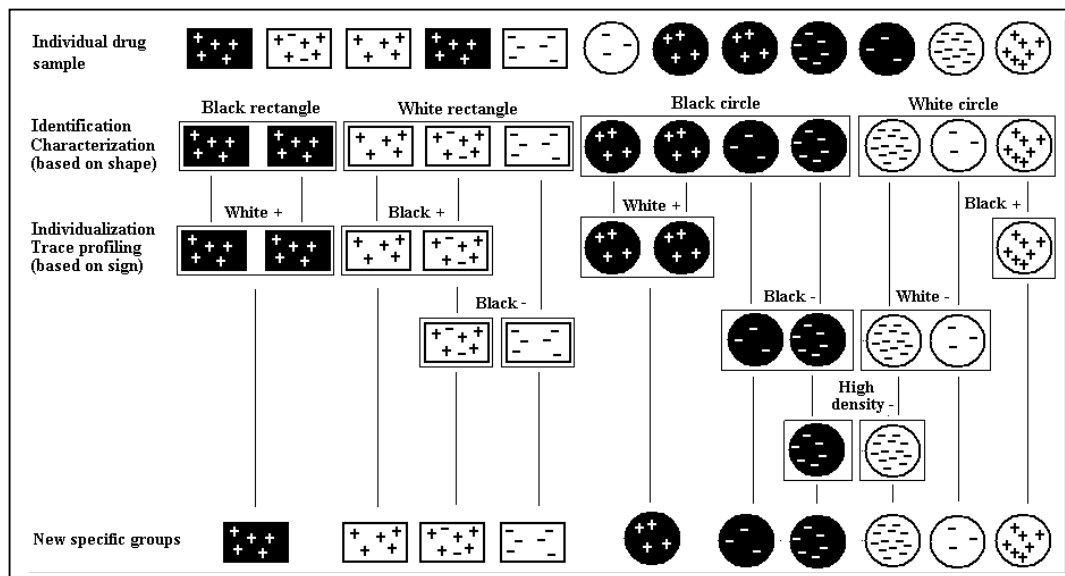


Figure 3.3: General scheme of forensic analysis for evidential purposes

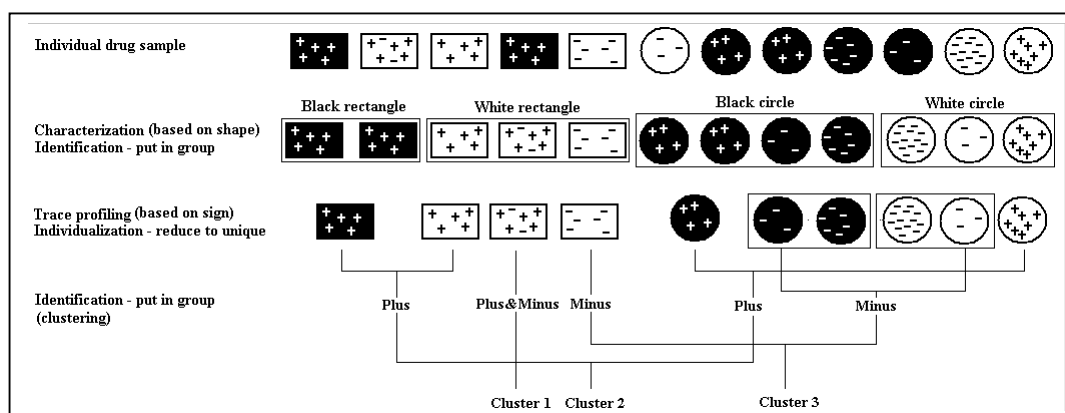


Figure 3.4: General scheme of forensic analysis for intelligence purposes

The unique drug profile is sometimes known as a fingerprint or signature which represents the identity of the drug entity and thus differentiating it from other drug entities. A fingerprint or signature is formed when all minor and major characteristics of a drug entity are collectively viewed and interpreted as a whole without distorting its parts (similar to the Gestalt's concept of background and foreground in psychology). When interpreting the sum of details, those not related to the drug's history such as contaminants and artifacts must be treated carefully. As these details tend to give false

interpretations, so one may always mistakenly aggregate/segregate an irrelevant sample into/from a group of samples having similar characteristics. Taking noscapine in the case discussed by Klemenc (2000) as an example, this opium-based alkaloid should theoretically be integrated as part of the overall sample fingerprint to determine the origin of illicit heroin. As the researcher found that noscapine was deliberately added as an adulterant rather than a co-extract from the opium, this extraneous information was then disregarded. The integration of noscapine in the dataset in this case will lead to misinterpretation as this opium-based alkaloid did not represent the drug origin. Hence, heroin profiling must have a clear goal as to what and how the data are used. Without the goal, extraneous information is hardly defined. For instance, the goal of determining the geographical origin of heroin tends to employ natural opium-based alkaloids for profiling. Neutral and acidic manufacturing impurities are useful for estimating the similarity between production batches at the manufacturing level.

A chemist must not underestimate the knowledge derived from profiling. It must be realized that unlimited information can be extracted from even a very simple packet of substance. But the success rate lies with the availability of advanced analytical instrumentation and the strength of the team involved in this profiling effort. Certainly, such laboratory-based effort, if pushed to the maximum limit, will only contribute one facet to the overall drug intelligence information system (Navaratnam & Hoe, 1984). Other facets shall include police information, case backgrounds and other monitoring work related to the drug activities.

3.5 Profiling of Illicit Heroin

Heroin profiling that aims to gather any possible piece of information for the purpose of finding similarities in the sample histories (e.g. origin, processing method, distribution links, etc) in the forensic intelligence framework thus distinguishes it from

the routine analysis of heroin. The profiling work is broad, more strenuous and detailed. Collins *et al.* (2007) proposed drug profiling as an intelligence-gathering exercise through which the forensic chemist accumulates as much as possible the physical and chemical information about a drug in order to assist law enforcement agencies in controlling the abuse and trafficking of the drug. For the profiling of heroin, laboratory-based profiling effort is inclined toward uncovering adulterants, production impurities, source impurities and contaminants. Details on the classification of these impurities have been described by Infante *et al.* (1999). To profile these target compounds, selective and sensitive techniques are crucial as most compounds characterized as signature impurities are only present in very trace amounts. Separation techniques by mechanical extraction and instrumental isolation are mandatory for profiling. The techniques eventually display individual components on a final output which constitutes a unique profile for the drug entity. To date, many creative and innovative profiling techniques and methods are swamping the regional and international journals to the extent that the drug chemist is confused with the choices available. The strengths and weaknesses of the commonly used analytical techniques and methods in heroin profiling have been reviewed (Besacier & Chaudron-Thozet, 1999; Dams, Benijts, Lambert, Massart & De Leenheer, 2001; Collins *et al.*, 2007) and this would help many amateur chemists to decide on the most suitable profiling methodologies. Many of the analytical methods were designed and modified by the local drug profilers to suit the nature of the local samples. Certainly, these methods were specifically optimized to achieve their specific goals of profiling and these goals generally refer to whether major organics, trace organics, residual solvents, trace elements or isotopes are of interest for intelligence purposes. Hence, some analytical methods may be straightforward while others tedious. During drug profiling, the chemist must identify the target compounds and their 'administration routes' through which these compounds enter the heroin

sample. As previously stated, these two aspects are critical for data interpretation because irrelevant information will lead to misinterpretation. For example, impurities entering through the laboratory analytical procedure are regarded as extraneous and irrelevant information. The target compounds must be those which are able to link the sample to an organized criminal activity such as the geographical origin, processing line or distribution link. Generally, the commonly encountered compounds are often introduced into the illicit heroin through the following routes (Table 3.2):

Table 3.2: Common types of compounds found in illicit heroin

Target Group	Compounds	Administration Route
Dangerous Drug	Heroin	The resultant target product processed via chemical conversion.
By product	3-MAM	Incomplete products during chemical conversion.
Alkaloid Impurities	Morphine, thebaine, codeine, noscapine, etc	Co-extracted during extraction step.
Acetylation product	Acetylcodein, etc	Co-converted from alkaloid impurities during chemical conversion.
Degradation product	6-MAM, dimethoxyacetoxyphenanthrene, etc	Degraded from heroin and other alkaloid impurities.
Solvent	Isopropanol, n-hexane, etc	Residual solvents added during extraction and chemical conversion.
Contaminant	Sodium, copper, etc	Metals from contaminated solvents, chemicals, equipment and atmosphere.
Cutting agent	Paracetamol, caffeine, etc	Diluents added to dilute heroin.
Artifact	Acetylparacetamol, etc	Artifacts produced during laboratory analysis.

Oftentimes, the term ‘impurities’ is used to describe the above-mentioned target groups except the dangerous drug, cutting agent and artifact. The impurities (trace/minor components and major components) together make up a unique history for a heroin sample and thus this phenomenon gives rise to forensic profiling. In most cases, the profiling nature of illicit heroin is very different from that of other drug entities since illicit heroin is commonly subjected to cutting by a multitude of chemicals/agents. Hence it is necessary to carefully select the opium-based alkaloids or manufacturing impurities and to investigate the trace levels of impurities which are extensively attenuated by the cutting process. The following highlights the steps and techniques frequently adopted by the heroin profilers to derive information from the illicit drug samples.

3.5.1 Preliminary Examination: Heroin Substance and Plastic Receptacles

Little concern has been given to the physical aspects of heroin substance as well as the associated receptacles and packages. It has long been a misconception that physical examination of the packages and the powdered drug like street heroin gives little or no useful information for forensic comparison as compared to the chemical characteristics. Most researchers cherish the idea that chemical data supersede physical data. Hung *et al.* (2005) for example only examined the basic physical aspects such as the color of the heroin substance and they placed more emphasis on the chemical aspects rather than the physical characteristics. In this context, a prejudiced analysis is inevitable, even Sanger, Humphreys and Joyce (1979) have ever cited that physical analysis of illicit drug preparations is largely limited to tablets and capsules. As a result, physical examination is seldom extended to irregular forms of substances such as street heroin. Many also do not regard physical data as one of the potential sources which can provide characterization to the sample as what chemical information does. In relation to

this, Milliet, Weyermann and Esseiva (2009) posited that physical characteristics are not considered sufficient to provide evidence of a link between seizures when presented in court.

As illicit heroin is always packed in a receptacle such as a plastic bag and plastic packet, the information associated with the receptacle in fact has a critical position in drug profiling. For example, a database for plastic bags and films has been set up in Australia, theorizing that the package profiles are able to trace the trafficking activities of illicit drugs (Roux, Bull, Goulding & Lennard, 2000). In their study, the physical information including thickness and weight of the package were shown to be useful in forensic intelligence. Discrimination based on general appearance and thickness of shopping plastic bags used by drug smugglers was one of the ensuing studies in this aspect (Causin, Marega, Carresi, Schiavone & Marigo, 2006). Besides, other package-associated aspects such as thumb-prints imprinted on the plastic package have also long been utilized by the enforcement body to link the sample to a particular owner. In addition to this, a novel experiment conducted by Zamir, Cohen and Azoury (2007) who extracted DNA from the heat-sealed areas of heroin packages has also enabled DNA profiling, maximizing the utility of the drug receptacle in forensic analysis. Inspection on the general appearance of plastic folding and wrapping also helps to establish initial identification. For example, when plastic packages similar to the 'square like' or 'amorphic' packages described by Zamir, *et al.* (2007) are seized, they are assumed to have come from countries other than Malaysia because this mode of packing is uncommon in Malaysia.

Sometimes, the forensic chemist might overly rely on the chemical information obtained from the analytical instrument. There is much truth in the saying that human brains supersede all other digital means because the final judgment always lies in the analyst's intelligence. Roux *et al.* (2000) demonstrated the strength of visual

examination over UV and FTIR in the analysis of plastic materials. For instance, the similarity of two plastic films can be quickly assessed by visually examining the texture and the thickness of the films. Without sound knowledge and experience, unfortunately, prejudice and subjectivity prevail in visual examination, leading to personal (subjective) viewpoints rather than objective judgments. To remedy this, UV, FTIR and differential scanning calorimetry (DSC) are inevitable, and they have eventually become the correct methods of choice for relatively quick analysis of polymeric films (Roux *et al.*, 2000; Causin *et al.*, 2006). Among these techniques, FTIR is particularly of high utility because it does not show significant variations in the results after the same films are subjected to different storage conditions (Gilburt, Ingram, Scott & Underhill, 1991). This excellent strength makes FTIR a robust method for film analysis. Its rapidity and minimum sample preparation also merit routine employment of FTIR in this field. In other cases, FTIR spectra coupled with striation marks and other physical characteristics found on the plastic films are potentially useful in estimating the trafficking route of illicit drugs (Sugita, Sasagawa & Suzuki, 2009). In relation to plastic film analysis, a more advanced discrimination method for plastic bags based on wide angle X-ray diffraction (WAXD) was also presented by Causin, Marega, Carresi, Schiavone and Marigo (2007). A better sensitivity can be achieved by thermal desorption capillary gas chromatography since this technique is far more sensitive to micro changes attributed to very minimum exposure of the films to daylight (Gilburt *et al.*, 1991).

The above cited literature is more pertinent to illicit drugs rather than to illicit heroin. These studies substantiate that the preliminary information derived from the drug substance and its package/receptacle can also help to characterize the drug. In fact, the complementary role of physical and chemical information has been demonstrated by Milliet *et al.* (2009) in methamphetamine profiling. To date, such a combined role in heroin profiling has not been reported.

3.5.2 Sample Treatment for Organic Impurities

Sample treatment is a crucial analytical step that serves to enhance the selectivity and sensitivity of the overall method by reducing the effects of interferents. Sometimes, the target drug might be masked by another compound due to their compatible physicochemical behaviour in the same analytical system. Perhaps, all careful steps have been taken but the target compounds are still not detectable because their signals are far too negligible compared to the interfering signals. In heroin profiling, sample extraction and derivatization are widely employed for the removal of these extraneous compounds. The decision on how the sample is treated depends on the target compounds and the purity level of the sample being studied. Generally, trace levels of impurities require extraction and pre-concentration steps while compounds with low volatility are subjected to derivatization. A genre of literature relating to sample extraction and derivatization has been reviewed by UNODC (2005) and they can be summed up as below:

Extraction: Simple and less thorough profiles of major compounds can be obtained by directly dissolving the illicit heroin either in N, N-dimethylformamide:ethanol (1:9), chloroform:ethanol:isopropyl alcohol (8:1:1), ethanol:water (4:1) or solely methanol. This simple method is sufficiently capable of extracting basic (alkaline) opium-based alkaloids present in relatively high levels. Therefore, it is unnecessary to perform basic extraction if these compounds are targeted for profiling. These direct dissolution procedures have been reported in the works of Kaa and Bent (1986); Zhang, Shi, Yuan and Ju (2004); Hung *et al.* (2005). In other instances, liquid-liquid extraction of neutral and acidic components into a single organic phase is required to segregate the targets from other interfering components present in the aqueous phase using

acids. The number and amounts of organic impurities extracted from the acidic aqueous phase are significantly more than those extracted from the basic aqueous phase (if a base/alkali is used for extraction) It is because most salt impurities in illicit heroin tend to form organic acids/conjugate bases in the acidic solutions. Several acids can be used for liquid-liquid extraction. Asahina *et al.* (1956); Law, Goddard, Japp and Humphreys (1984) employed hydrochloric acid to extract morphine and acetylthebaol respectively. Due to the polar nature of sulfuric acid which in turn calls for a minimal requirement of the reagent, Strömberg *et al.* (2000) utilized this acid to facilitate extraction of more than 16 impurities. In addition, Neumann and Gloger (1982); Allen, Cooper and Moore (1984); Myors, Crisp and Skopec (2001); Collins *et al.* (2006); Morello, Cooper, Panicker and Casale (2010) also utilized sulfuric acid for liquid-liquid extraction before the impurities were derivatized. Extraction with acid must be carried out with great care since the samples are vulnerable to degradation at extreme pH (< pH 3). In terms of organic solvent, toluene is usually used in acidic extraction because this solvent is obtainable in high purity (Neumann & Gloger, 1982). Besides, other extracting solvents including ether, diethylether, dichloromethane and petroleum ether have also been recommended (Myors *et al.*, 2001; UNODC, 2005; Collins *et al.*, 2006; Morello *et al.*, 2010).

Derivatization: As the organic impurities are less volatile for GC analysis, they have to be treated by derivatization. Some analyses have utilized this method with the aid of N-methyl-N-trimethylsilyltrifluoroacetamide (MSTFA), benzoyl chloride in chloroform or N, O-bis-(trimethylsilyl)trifluoroacetamide (BSTFA) containing 1% trimethylchlorosilane (TMCS) in dichloromethane to give better peak quality for the heroin profile. Derivatization with direct

dissolution is included in the studies of Klemenc (2000); Esseiva, Dujourdy, Anglada, Taroni and Margot (2003). Very often, derivatization is employed to derivatize neutral and acidic impurities after the liquid-liquid extraction. This procedure has been reported in the literature from the studies of Neumann and Gloger (1982); Allen *et al.* (1984); Myers *et al.* (2001); Collins *et al.* (2006); Morello *et al.* (2010).

3.5.3 Instrumental Analysis

Instrumental analysis serves a dual role in narcotics laboratory. First, it is essentially a valid means to identify and quantify the target compounds. Second, with its discriminative power, instrumental analysis is an important tool for generating a fingerprint output for a drug sample. This can be achieved by techniques ranging from a simple planar chromatography to advanced instrumentation. For the classical planar separation, Casa and Martone (1986) noted that even the simplest HPTLC plates with UV spectra were sufficient for determining the qualitative compositions of the illicit heroin. As planar chromatography can rapidly screen fluorescent compounds in the sample, thebaol, acetylthebaol and phenanthrene derivatives of thebaine can be easily identified as fluorescent spots by UV on a TLC plate (Chiarotti, Fucci & Furnari, 1991). These older methods are not preferably chosen in today's profiling plan because they do not provide sufficient selectivity and sensitivity for highly diverse impurities in a highly complex sample matrix.

To analyze alkaloids and adulterants, GC is the technique of choice since it utilizes a smaller sample size for analysis. Dating back to the 1970s and 1980s when trace manufacturing impurities were not extensively chosen for profiling, GC-FID had been primarily employed to analyze codeine, morphine, acetylcodeine, heroin and other adulterants (Sanger *et al.*, 1979; Narayanaswani, 1985). Later, when GC-FID and GC-

MS proved capable of isolating a rich amount of manufacturing impurities (Neumann & Gloger, 1982; Allen *et al.*, 1984), they have become popular techniques in heroin profiling. Besides, Strömberg *et al.* (2000) also demonstrated that GC-FID showed repeatable and reproducible for 16 impurity peaks in the intra and inter-laboratory analyses in a harmonization study. This is testament of the stability of the instrument and hence its robustness in analyzing heroin samples of a common origin. In another study done by Dufey, Dujourdy, Besacier and Chaudron (2007), GC-FID gave better results for derivatized opium-based alkaloids than for liquid-liquid extracted trace impurities. In this research, a subsequent study also emerged to prove the ability of six major opium-based alkaloids in giving sufficient sensitivity for sample clustering. When major alkaloids (which are present in high levels) are used, this also minimizes the need for a large sample amount for analysis compared to trace impurities that are only determinable at a higher sample weight. A similar study targeting five major alkaloids and three adulterants with direct dissolution was also performed by Hung *et al.* (2005) using GC-MS. Zhang, D. *et al.* (2004) on the other hand classified five hundred heroin samples seized in China into nine groups based on the opium-based alkaloid content and other characteristic adulterants utilizing chiefly anhydrous ethanol. It is uncommon to test the drugs on a garment viewing that the task of getting reliable results from this unusual exhibit is somewhat challenging. However, a toxicological case analyzing textile samples bearing sebaceous excretion of opiates proved possible with GC-MS (Tracqui, Kintz, Ludes, Jamey & Mangin, 1995). It is well known that high resolution is an all-important criterion to reveal the diverse peaks in a single profile. Highly discriminative profiles will help enhance discernability among a large number of samples and thus minimizing coincidental match. After extraction, about 70 impurity peaks were possible with the method described by Neumann and Gloger (1982), utilizing chiefly GC-FID. The same chromatographic outcomes with about 35

impurity peaks were also obtained by Morello *et al.* (2010). Myors *et al.* (2001) used GC-MS to construct a comprehensive library of over 649 organic impurities found in 46 purified Southeast Asian and 8 non-purified Southeast Asian heroin samples. In the study of Collins *et al.* (2006), a sterol-like molecule was detected by GC-MS among the impurity peaks extracted from the illicit heroin seized in Korea. Another advantage of the GC technique is that a wide range of capillary columns can be chosen to enhance separation selectivity. Kaa and Bent (1986) demonstrated that sugars including glucose, sucrose, lactose and mannitol that are not detected by the routinely employed columns can be easily detected as trimethylsilyl (TMS)-derivatives by a GC preinstalled with a 15% Dexsil 300 column. In terms of stationary phase, capillary columns such as BP-1 quartz, BPX-5, SE-54 glass, DB-1, and Ultra-2 were frequently employed in the above cited studies. GC remains popular and widely accepted in many narcotics laboratories because it offers a significantly shorter analysis time with higher throughput.

Liquid chromatography compensates for the shortcomings of GC. For instance, GC is relatively poor at resolving 3-MAM from 6-MAM, but the method employed by Zelkowics, Magora, Ravreby and Levy (2005) showed fairly good resolution of these compounds in the heroin profiles obtained with HPLC coupled to a photodiode array detector (PDA). Similarly, Collins *et al.* (2006) utilized HPLC for the determination of major alkaloids present in the illicit heroin seized in Korea. In fact, the classical use of HPLC coupled to UV and fluorimetric detection systems is credited to the work of Huizer (1983b) who reported the ability of this technique in discriminating heroin samples of the same seizure. The ability of HPLC to isolate involatile compounds and large polar compounds is another advantage of this technique. Unfortunately, HPLC usually gives lower resolution and requires a longer analysis time when a short column length and viscous liquid mobile phase are used. These problems were promptly rectified by Law *et al.* (1984). In their study, the discriminatory power and analysis time

were improved to allow the separation of up to 15 commonly occurring impurity components in less than 10 min. HPLC is however unfavorable to most chemists because of the need for larger solvent volumes which will also pose greater health and environmental hazards.

Chromatographic techniques are imperative in profiling chiefly because they offer fingerprint chromatograms for comparison. MECC is another forensic tool that gives fingerprint outputs mimicking chromatograms for quick interpretation (Anastos *et al.*, 2005a). MECC is known for its short analysis time and portability for field testing. Similarly, electrophoresis was also employed to distinguish a range of carbohydrates in illicit heroin in less than 8 min (Anastos *et al.*, 2005b). Instead of GC and HPLC, most major alkaloids could also be profiled using electrophoresis (Collins *et al.*, 2006). The only disadvantage of this technique is the tedious preparation of a buffer solution.

FTIR on the other hand deciphers an illicit heroin sample as a unique spectral output (Ravreby, 1987) and this provides another alternative technique for heroin profiling. FTIR sums up the absorption bands of all constituent components in the sample. However, FTIR fails under this obligation when the sample is dominated by a high level of adulterant.

The unintentionally introduced metals could also be a potential source of profiling information. Major and trace metals including calcium, cadmium, copper, manganese, iron, zinc and others have been investigated by atomic absorption spectrometry (AAS) and inductively coupled plasma atomic emission spectrometry (ICP-AES) (Chiarotti *et al.*, 1991; Infante *et al.*, 1999; Bora, Merdivan & Hamamci, 2002). Metallic contaminants are significant for profiling especially when the samples are relatively pure. A total of 73 trace elements were determined using very small amounts of illicit heroin seized from the Southeast Asian and non-Southeast Asian countries (Myors *et al.*, 1998). In the study, a rich amount of elemental data could be

obtained in a very short analysis time with the aid of inductively coupled plasma mass spectrometry (ICP-MS). Despite the usefulness of ICP-MS, this method is not foolproof especially when traces tend to exhibit variability in their findings. In view of this, Myers *et al.* (1998) suggested selecting only elements with high precisions for profiling. On the other hand, 15 trace elements determined by neutron activation analysis (NAA) also proved useful in clustering 62 heroin samples into their origins (Zhang, Z. Y. *et al.*, 2004). For quantification, some metals may also fall below the quantification limits which in turn reduce the richness of chemical data. Hence, the detection and quantification of isotopes may help to rectify this issue. Nuclear magnetic resonance spectrometry (NMR) was employed by Hays, Ramaud, Jamin and Martin (2000) to study isotopic deuterium in illicit heroin. This technique is not commonly employed because a tedious purification procedure is required. Recent technology has also enabled drug profiling to distinguish samples based on isotopic differences. This has been demonstrated by Casale *et al.* (2006) using isotope ratio mass spectrometry (IRMS).

NMR is certainly a method of choice for structural elucidation of unknown components purified from the heroin sample. Methamphetamine profiling, for instance, relies on the discovery of the new compounds recovered from the samples to keep abreast with the emergence of new synthetic routes. Similarly, identification of unknowns is a pragmatic approach in heroin profiling owing to its semi-synthetic nature. Many newly identified impurities related to the processing of illicit heroin found in the 1980s were characterized by NMR (Allen *et al.*, 1984). As conversion of organic impurities may occur during processing, Toske *et al.* (2006) employed NMR in addition to other instrumental techniques to study various neutral impurities and the degradation pathway. Ideally, these identified impurities can be used to establish an even more unique chemical fingerprint, rendering a highly discriminative profile for the sample.

Headspace analysis of occluded solvents such as acetone, xylene and diethyl ether is another important research area in forensic intelligence. The solvent information is highly informative for synthetic drugs as well as the processed substances since they involve chemicals and solvents in the manufacturing procedure. As for heroin, 25 occluded solvents dissolved in aqueous sodium sulfate were identified and quantified using GC-MS with an ion trap detector (ITD) by Morello and Meyers (1995). Later, 11 occluded solvents in carbon disulphide eluted from an activated charcoal strip were determined by GC-FID (Cartier, Gueniat & Cole, 1997). These data serve as significant indicators for the current heroin processing methods since large amounts of solvents are often used in opium processing and the production of heroin. Collins *et al.* (2006) used the solvent data given off by the purge and trap GC-MS to predict the association of typical solvents with the manufacturing regions.

3.5.4 Stability

Sample stability is a major concern in drug profiling. Post-processing hydrolysis can readily occur in those samples containing non-bound water or excess acid (UNODC, 2005). In this case, diamorphine will be naturally hydrolyzed to 6-MAM over a period of time, with subsequently decreasing diamorphine content while the MAM content increases. The conversion between diamorphine, 3-MAM and 6-MAM in a home baked heroin sample was demonstrated by Sibley (1996). In the study, it was found that 6-MAM was a decomposition product of diamorphine when the samples were not stored under proper conditions while 3-MAM was only an intermediate product derived from the acetylation of morphine. It is therefore pivotal to consider the total morphine (diamorphine + MAM + morphine) content rather than the individual components while estimating the similarity between samples since interconversion between these compounds can occur. In this regard, Zelkowics *et al.* (2005) have

reassured the importance of this data normalization procedure in obviating the effects of cutting and decomposition.

The high humidity condition in Malaysia would hypothetically promote the hydrolysis of diamorphine especially when proper storage is not practiced. There have been some studies to examine the extent to which this hydrolysis process affects the validity of the analytical results. It was reported that over a 3-month storage period at room temperature using diamorphine or MAM as one of the peaks in normalization did not affect source identification (Zhang, D. *et al.*, 2004). However, the authors strongly recommended correction of the diamorphine content if samples have been kept for more than 3 months after which the decomposition effects become significant. Similarly, Strömberg *et al.* (2000) regarded the stability issue with trace impurities in illicit heroin over a 4-month period as unimportant if proper statistical pretreatments are carried out. Heroin samples in solid form also showed larger variations in their alkaloid content compared to that in the solution form (Zhang, D. *et al.*, 2004). In fact, greater sample stability can be achieved with proper storage. According to UNODC (2005), heroin hydrochloride that is free of unbound water or acid and stored in the dark at ambient temperature using a tightly sealed container will degrade at a considerably slower rate. Also, it is advisable that granular heroin samples should be kept in such a physical form if analysis is not done immediately. The small surface-to-volume ratio of the granule which serves to help restrict possible contact of diamorphine with the atmospheric moisture will in turn help protect diamorphine against hydrolysis to a considerable extent.

Other than sample stability, Zelkowics *et al.* (2005) also reviewed some possible means of artifact production which might lead to data misinterpretation. They asserted that the use of methanol will convert diamorphine to 6-MAM by transferring one acetyl group to paracetamol, forming acetylparacetamol.

Hence, greater stability or lower degradation can be achieved if the drug chemist takes proper measures to keep decomposition to a minimum. The heroin sample can be best preserved in a cold and dry cabinet without direct exposure to sunlight.

3.6 Chemometrics

Statistical treatment is a compulsory step to transform the collected data into more meaningful and practical information for decision making. The symbiosis of chemistry and statistics (also termed as ‘chemometrics’) in forensic analysis is pivotal in at least three aspects, namely laboratory automation, descriptive analysis and data reduction. In the laboratory, automated chemometrics involves converting unintelligible raw data signals into more meaningful processed data using a software program. The final outcomes are usually expressed as the instrumental readings such as spectral absorbance, analyte concentration calculated from a calibration curve, etc. These manipulative procedures are commonly integrated in the software of the instrument. The next use of chemometrics involves manual manipulation of the raw or instrumental data into different forms to address the objective of the analysis. In practice, the data will be converted into some representative figures, graphs and tables using additional statistical software to aid the decision making process. With a more advanced software program, data reduction is specifically carried out to reduce multivariate data into manageable dimensions which often contain the most meaningful information. In profiling, these variability rich dimensions are useful to oversee the overall relationships of the samples.

Automated chemometrics is routinely employed by chromatographic and spectrometric techniques. Graphical chromatograms and spectra are the result of the integration of data points. In so doing, the fingerprints of individual samples can be obtained in graphical forms and comparison can be easily made. For example, the

differences between a heroin sample before and after it has been cut with adulterants can be made directly clear by comparing their chromatograms (Strömberg *et al.*, 2000; Zelkowics *et al.*, 2005). Any similarity and discrepancy in the samples can also be easily examined visually on the graphical outcomes. To do this, a traditional superimposition of two or three graphical data can be employed to determine the closeness/similarity of these samples. For example, the FTIR software is able to provide such a comparison to allow simultaneous multiple superimpositions. However, this technique has to be dismissed when the number of data (e.g. too many spectra have to be compared) becomes unaffordable with superimposition.

For the quantification of analytes in a sample, calibration curves based on simple regression plots are commonly integrated in the modern software. When an internal standard is used in the analysis, the curve enables the instrument to estimate the analyte content based on the area ratio through which errors arising from the analytical procedure can be largely minimized. This technique is also recommended by UNODC (1998) for the analysis of illicit heroin.

In terms of method optimization, chemometrics helps eradicate unnecessary parameters while select the most important ones for decision making. Dujourdy and Besacier (2008) demonstrated how statistics helped them choose the critical parameters to optimize a method for cocaine profiling. Similarly, all other profiling methods will have to work along with statistics for method optimization. With chemometrics, better decisions can be made easily and unnecessary financial waste can be avoided.

Post-analysis data manipulation aims to transform the data into another form from which inferences can be derived. Graphical representations are typical of this procedure. Terrettaz-Zufferey, Ratle, Ribaux, Esseiva and Kanevski (2007) summarized the cutting agents found in illicit heroin using a graph theory to infer co-occurrence and evolution of the cutting agents throughout the sampling years. In their study, the

constructed graphs may appear complicated but they are indeed comprehensible as interpreting the graphs is very straightforward. Likewise, Hung *et al.* (2005) used a pentahedron to present the purity level of diamorphine and other opium-based alkaloids. The pentahedron is not only useful in summarizing the alkaloid content, but also practical in showing the general patterns of the four types of illicit heroin encountered in Vietnam. Of course, this also incurs simple statistical treatment to convert the data into percentage in order to make them comparable on the pentahedron. In addition, histograms and box-plot are inevitable to represent the overall frequency of cases especially when too much data must be displayed at once. Such statistical illustrations are useful to provide descriptive details such as mean, median and interquartile values about a population.

To determine the similarity level between samples, the alkaloids or manufacturing impurities must be normalized to yield various constant quotients to minimize the effects imparted by the cutting agents as well as errors from the analytical procedure. Without normalization, samples from a common source will be mistakenly separated since cutting effects and analytical errors usually alter the absolute values of the alkaloids. In addition, improper storage of the samples promotes hydrolysis of heroin and hence leads to differences in the alkaloid composition despite similar/common origin. As discussed earlier, diamorphine will undergo partial decomposition under favorable conditions. To minimize all the above-mentioned errors, the individual opium alkaloids should be normalized to the sum of heroin-MAM, heroin-MAM-morphine, morphine-codeine or heroin-acetylcodeine, all of which proved useful in establishing the origin of illicit heroin (Sanger *et al.*, 1979; Narayanaswani, 1985; Zhang, D. *et al.*, 2004; Zelkowics *et al.*, 2005). More useful outcomes can be achieved by presenting two or three variables (e.g. the normalized data) on a two- or three-dimensional graph since graphical data distribution is more meaningful to imply

sample relationships (Hung *et al.*, 2005; Collins *et al.*, 2006). This concept is similar to principal component analysis (PCA) – a statistical technique that utilizes more than three variables or multivariate data.

Other mathematical manipulations have also been employed to evaluate the degree of similarity between different drug samples. Numerical distances between two data points on a graphical plane are a good measure to determine the closeness between the samples. The smallest distance between two points means the closest relationship between them. Distance assessment was performed by Esseiva *et al.* (2003) and squared cosine method was shown to be most reliable for heroin sample comparison in the study because it showed minimum false positives and false negatives. With the aid of distance measures, hierarchical cluster analysis (HCA) using dendrograms/tree diagrams is another technique to graphically rationalize the hierarchical links among a large pool of samples at different degrees of similarity. Such statistical approach has been extensively used to link heroin samples on the basis of organic impurities and metal traces (Myors *et al.*, 1998; Myors *et al.*, 2001). Alternatively, PCA is an objective statistical technique to provide relative graphical relationships between samples. In profiling, PCA is used to decompose a large set of normalized data into practically two to four components that normally contain the highest data variabilities. Based on the graphical distances represented on a two- or three-dimensional graph, sample relationships can be quickly assessed. This technique was demonstrated by Myors *et al.* (1998); Hays *et al.* (2000); Bora *et al.* (2002); Ratle, Terrettaz, Kanevski, Esseiva and Ribaux (2006) using chemical data obtained from the illicit heroin. Other approaches including multi-layer perceptron, probabilistic neural network, radial basis function network and k-nearest neighbors (KNN) method were also successfully applied to illicit heroin seizures for pattern analysis (Ratle *et al.*, 2006).

Instead of the conventional use of analysis of variance (ANOVA), Pearson correlation and cosine correlation operating on intra-batch and inter-batch variabilities are often undertaken for profiling studies (Ioset, *et al.*, 2005; Dufey, *et al.*, 2007). These techniques are useful to estimate the association between samples based on the selected variables/components. A high association between two samples would suggest that they could have come from a common source (e.g. origin or batch). In this regard, Infante *et al.* (1999) employed correlation analysis to estimate the co-occurrence of metal contaminants in illicit heroin.

3.7 Forensic Intelligence

As has been mentioned in the previous sections, drug profiling is for forensic intelligence. But what is forensic intelligence? This has a strong connection with artificial intelligence which in general describes how computers mimic human intelligence in pattern recognition (Sharaf, Illman & Kowalski, 1986). Generally, intelligence strives to categorize and predict a system's properties which are not directly measured, based on a set of measurements made. Categorization on the other hand is done with supervised or unsupervised pattern recognition. Supervised pattern recognition requires several training sets to provide identification characteristics for the unknowns to be grouped accordingly. Without such prior knowledge provided by the training sets, the unknowns can be assigned based on the degree of similarity and this technique is called the unsupervised pattern recognition. Statistically, this is often associated with the reduction of dimensions (variables) from hyperspace to two or three manageable dimensions so that the human's mind is able to comprehend the system as a whole and make predictions. In forensic drug intelligence, these predictions usually centre on the sample relationship and sample grouping (refer to Section 3.6 Chemometrics). With these statistical predictions, the general network and distribution

activities of an illicit drug can be presented in an organized way. The predictions however are not always correct. It is statistically prone to errors or uncertainties.

Forensic intelligence has been playing a vital role in all criminal cases. The need of an intelligence system in supporting law enforcement bodies is propounded by Godwin (2001):

“...Lack of a fully developed strategic and tactical intelligence capacity seriously hinders the ability of a law enforcement agency to accurately measure and prevent organized, serious crime within its jurisdiction or to anticipate crime threats that can significantly affect the jurisdiction...”

Very commonly, forensic intelligence operates closely with a database, through which one can extract new knowledge to make predictions. Such knowledge may be of judicial interest for convicting or absolving the accused. Or it could be a good tool to illustrate the pattern and trends of the crime of interest. The tyre tread pattern found at a crime scene for example can be searched against an updated database to derive knowledge about the manufacturer, year and production line for the tyre. Subsequently, this knowledge would help the law enforcement unit to follow up on their investigative work immediately or in future before the criminal activity festers. In drug control, Australia has established a database for plastic bags which can be searched to find similar plastic bags that are used for packing illicit drugs (Roux *et al.*, 2000). With this knowledge, it enables the enforcement unit to trace the trafficking routes of the drug with confidence.

Forensic intelligence is a broad term to include all kinds of predictive activities in the forensic framework. Godwin (2001) defines its scope as follows:

- **Criminal intelligence:** Obtain conclusions resulting from the analysis of criminal data and information collected on known or suspected persons involved in a crime.
- **Strategic intelligence:** Provide the scope and character of a crime which in turn bring about prevention, containment, attrition or displacement to reduce the harmful effects caused by such criminal activity.
- **Tactical intelligence:** Retrieve immediately usable information to support investigative activity on a short term basis.
- **Operational intelligence:** Detail patterns, modus operandi and vulnerabilities of criminal organizations by understanding the workings of the criminal enterprise.

Of all types of intelligence, drug profiling is mainly concerned with strategic and tactical intelligences. For strategic purposes, the data will assist in predicting organized crime and criminal activities. For tactical purposes, it aims to establish the relationships between seizures, cases or events. The relevant details regarding these aspects have been included in the literature (Zingg, 2005; Locicero *et al.*, 2008; Weyermann *et al.*, 2008).

To meaningfully perform drug intelligence, several aspects must be taken into consideration. Specifically, speed and cost are the two significant factors that must be considered by the profiling laboratory. In most cases, the profiling program must be economic and can afford a rapid analysis in a timely manner. In contrast, deviation from the right track of intelligence work is very time wasting and costly. Therefore, a well planned and systematic intelligence process must be in place. Table 3.3 compares two procedures involved in the intelligence process recommended by Godwin (2001) and Ioset *et al.* (2005).

Table 3.3: Comparison of two procedures involved in the intelligence process

Step	Intelligence process by Godwin (2001)	Step	Intelligence process by Ioset, <i>et al.</i> (2005)
1.	Planning the intelligence effort involving the setting of priorities and specific requirements for collection of information	1.	Sampling: small quantities of samples are selected for analysis. It is important that all entities involved use the same methods in the same manner, with similar facilities so that the results obtained will be comparable
2.	Directing the intelligence effort in accordance with agreed plans or guidelines		
3.	Collecting pieces of information from various sources	2.	Identification of physical and chemical characteristics
4.	Evaluating that information as to its accuracy and usefulness		
5.	Collating or systematically organizing the information for storage and retrieval	3.	Interpretation: the data are arranged in a memory. Seizures are not stored individually but are collated and grouped in classes according to similarities of the profiles identified
6.	Analyzing the information to determine its meaning in reference to a criminal investigation or assessment	4.	Intelligence: computerized techniques for recognizing patterns in large quantities of data can be applied. Such patterns should draw attention to specific data sets of interest
7.	Disseminating or reporting the findings of the analysis	5.	Action to be taken

Generally, any intelligence process should start off with a clear intelligence plan that stipulates the ultimate goals for the data collected. The ultimate use of the collated data (e.g. to establish distribution links or to determine drug origins) will therefore call upon different data handling techniques (UNODC, 2005). Characterization and profiling techniques will be quite different if the goals set by two different laboratories do not coincide. For example, the search for different kinds of opium-based alkaloids in illicit heroin is prioritized for the determination of geographical origin. In contrast, occluded solvents are profiled because they are meaningful for comparing heroin

processing methods. More importantly, when all relevant data are collected, the profiling effort should end with a memory (or database) on which the data are arrayed in a useful pattern, pursuant to the goals set. The database containing chronicles of old case files is particularly useful to evaluate whether an old incident is still prevailing. For example, a new illicit heroin submitted can be compared with those seized five years ago to know if the same producer is still operating in the current distribution network. Case-to-case or seizure-to-seizure linkages established within the database can also indicate the levels of drug operation (e.g. wholesale or retail) in the distribution network. This knowledge is useful to guide the subsequent investigation steps and suggest priorities for action (Ioaset *et al.*, 2005).

From a strategic perspective, the detection of some components that do not belong to the location under investigation will help shift the focus of the investigation to another direction. For example, by identifying the dyes not authorized in the country where the pills are seized, the analysis of dyes in illicit pills will therefore infer a foreign production (Goldmann, Taroni & Margot, 2004). Besides, the general network formed by the individual linkages is of great value to assess the extent of a drug distribution activity over a period of time. This is presented by Zingg (2005) who achieved several networks of ecstasy pills using physical and chemical characterization details.

In drug intelligence, classifying materials from different seizures into groups will fundamentally serve the following purposes (UNODC, 2005):

- identifying the number of origins of samples, whether within a country or internationally based
- identifying the points of distribution and distribution networks

- identifying output from new illicit laboratories and monitoring common methods used for drug manufacture
- understanding the trends in drugs of abuse
- differentiating illicitly manufactured drugs from those diverted from licit sources

Furthermore, it can also assist in

- understanding the histories and experiences of the samples
- discovering new methods in drug manufacturing adopted by clandestine laboratories

To achieve the above purposes, statistical classification of drugs is widely practiced. A classical example of drug intelligence using statistical approach was demonstrated by Tanaka, Ohmori, Inoue and Seta (1993). In the study, a very low similarity index of Euclidian distance between two groups of samples which had been assumed to have a strong connection had contradicted the preliminary conjecture. Other classification techniques often employ PCA and HCA to estimate groups based on statistical distances (Myors *et al.*, 1998; Hays *et al.*, 2000; Myors *et al.*, 2001; Bora *et al.*, 2002). Qualitative findings also play a significant role in forensic intelligence. On the basis of alkaloid ratios and the presence of diethyl ether and ethyl acetate in the heroin samples seized in Korea, Collins *et al.* (2006) predicted that these samples were likely to have come from Southeast Asia.

Recent drug intelligence emphasizes a harmonized profiling method. In this respect, regional laboratories should collaborate to work out a harmonized profiling plan so that the drug profiles obtained in their respective laboratories can be compared.

Following this global call, a harmonization study for heroin profiling was already performed by Strömberg *et al.* (2000).

3.8 Metaphysical Review of Forensic Drug Intelligence: Heroin Profiling

It is understood that forensic intelligence is a complex activity. However, its principle could be made simpler when forensic drug intelligence is explored from a new perspective called metaphysics which essentially provides a fundamental nature for this complex framework. Metaphysics (also known as “ontology”) pioneered by Aristotle, simply means ‘beyond physical’. This branch of philosophy investigates the fundamental principles of reality and the ‘being *qua* being’ (or being as such) which rule the physical and abstract aspects of everyone’s life. The metaphysical truths are generally verified by science which is a rational approach to gather the fragments of reality and piece them together into an absolute truth. In most cases, metaphysics is thought to be the ultimate refuge for things that are unexplainable or unsolvable by any other laws, theories and concepts. The existence of God for example, is scientifically unproven. This issue is eventually explained by theology, a branch of metaphysics that acknowledges an unseen truth based on the events and facts in every day’s life. Without science, the metaphysical truth can also be checked by logic. In chemistry, Scerri (2005) used a metaphysical concept, ‘unobservable substances’ to describe elements (referring to those in the periodic table) that possess the properties of ‘abstract entities’ so that such unseen elements become more comprehensible. The existence of these unobservable substances is readily proven with science and logic. Based on this concept, the unobservable distribution links could also be revealed by chemometrics.

As a continuing contribution to understanding forensic intelligence from this fresh perspective, it is worth shedding some light on the past work of drug intelligence to highlight the relevant metaphysical concepts in this framework. In fact, the

combination of metaphysics and forensic drug profiling is the complementary side between (or the gray zone of) the two specific aspects under the broad theme of forensic intelligence (Figure 3.5). Both aspects mutually rely on each other to explain their underpinnings. In the following discussion, various metaphysical explanations relating to the scientific evidence of drug profiling are integrated in this review. Five metaphysical aspects including the basic notion, law of identity, causality, necessity and holarchy which constitute philosophical bases for forensic intelligence and drug profiling are emphasized.

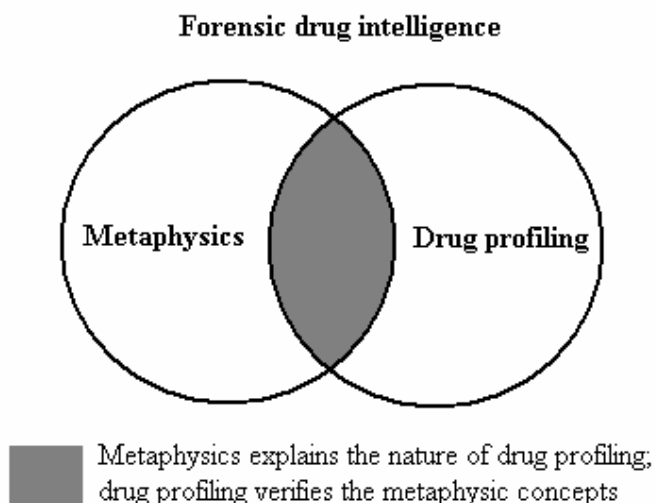


Figure 3.5: The mutual relationship between metaphysics and drug profiling in the forensic drug intelligence framework

3.8.1. Forensic Intelligence Stems From Basic Notions

Metaphysical notion is a basic notion which does not rely on another for its explanation or validation as it is by nature fundamental enough for it to be proven by others. In essence, Newton's law of gravity is a basic notion owing to its universality and validity. With the basic knowledge of this Newtonian notion, Einstein's General Relativity emerged to explain abnormal effects not accounted for by Newton. Hence, a basic notion also serves as a trigger for subsequent investigations. In forensics, two

scientific notions, namely Locard's principle of transfer and Kirk's principle of individualization are the two central notions responsible for the validity of all investigative work.

Locard's principle is a standalone notion. Transfer could be explained by adhesion between two interacting objects. When adhesion fails, Locard's principle can explain transfer occurring between two scientifically unrelated objects. Consider flying objects such as fiber, hair and body scent emanating from a person who has come into contact with an environment, for these to remain in the atmosphere devoid of attractive forces (e.g. vacuum) responsible for the adhesion between two objects faultlessly makes 'every contact leaves traces' valid. However, many of these traces are inadvertent residues. A notable example is the unnoticeable fingerprints which have long been utilized by the law enforcement officer to link seized samples to the trafficker. As part of the heroin intelligence work, the principle of transfer enabled Zamir *et al.* (2007) to extract unseen DNA from the heat-sealed areas of heroin containing receptacles for DNA profiling. This work served as an impetus for future investigation which involves the search of transferred clues that are not necessarily visible to human eyes. In line with this belief, drug profiling has been implemented to find unseen clues or impurities that make up a significant proportion of a heroin entity (LeVert, 2006). Without quality control, the production of heroin and the drug traffickers themselves unknowingly leave minute traces in the final products, paving the way for more extensive investigative work to associate samples with suspects, other seizures, processing methods and geographical origins. Except the active ingredient (e.g. heroin) and adulterants intended by the drug dealer, the transferred clues are mainly the opium alkaloids, by-products, solvents and metals. Hence, the source leaves traces of its natural commodities, the manufacturer leaves traces of unreacted ingredients and the distributor leaves traces of contaminants, all contributing to a pool of traces for the forensic scientist to discover

and decode. These transferred impurities presented as drug profiles will provide useful information to the law enforcement unit to oversee illicit drug activities.

An entity is a unique being. Kirk's principle of individualization contends that nothing is identical. In other words, similar objects should exhibit close agreement in their physicochemical properties. In this light, Kirk's principle must also work with Leibniz's Law (if x is identical with/similar to y, x and y must share all their properties) in distinguishing between the dissimilar as well putting the similar items together at the macro level (putting in groups). Further, guided by Kirk's principle alone, individualization (reduction to unique ones) of the fragmented parts of a common source is based on their unique properties in a micro sense. This is done successfully when the parent source contributes a common set of 'individualistics' to its parts which first segregate them from other sources and help group them under the parent source. Therefore, identification serves to distinguish between units within a common group obtained at the identification step. Undoubtedly, the concepts of identification and individualization derived from the Kirk's notion have gained a worldwide acknowledgement for all forensic comparisons to become valid and to provide a foundation for source determination in forensic intelligence.

In line with Kirk's principle, drug profiling is an analytical procedure for the identification and individualization of a drug entity. As the drug samples are getting more complex, this calls for simple and sensitive analytical methods capable of retrieving more individualistic features for detailed characterization of the seized drugs.

Overall, these two basic notions are the mainstay of forensic intelligence without which comparison is meaningless. Drug profiling, when critically appraised, slowly leads the forensic practitioner to discover the metaphysical nature of illicit drugs and illegal drug markets. With a better metaphysical knowledge about the illicit drugs, potential complications in drug profiling would still be manageable.

3.8.2 Law of Identity

The law of identity in metaphysics argues that each object must have an identity with a distinct nature to exist. A being is identified based on its unique properties and behaviors. According to Esfeld (2003), this being should also meet the following criteria:

- i. they have a spatial-temporal location
- ii. they are a subject of the predication of properties each (the uniqueness of the properties is self-evident)
- iii. there are some qualitative properties by means of which each of these objects is distinguished from all the other ones (at least the spatial-temporal location is such a property).

Hence, for a drug to exist as a unique being, it must fulfill these criteria. Drug chemists utilize drug profiles to achieve the third criterion in order to distinguish between samples and seizures.

Each entity is made up of many fundamental building blocks, which are the smaller entities (van Brakel, 2000; Harré, 2005). The identity of the entity is therefore the sum of the identities of the smaller entities, with each demonstrating its unique characteristics. Specialists of different fields name objects based on their unique properties, rendering them identifiable with their identities. In this respect, determining the identity of a compound is the main objective of analytical chemistry. For example, GC-MS employed in drug analysis gives unique identities to thousands of unknowns in a sample. On the other hand, NMR is used to investigate unknown compounds with the aim that International Union of Pure and Applied Chemistry (IUPAC) names can be given to distinguish the new compounds from the others (Eller, 2006). In terms of drug

identities, many chromatographic methods have been invented to profile a similar type of drug so that two different drug entities not from a common source will disclose their identities. To this end, current analytical techniques conclude the identity of a drug entity based on the sum of unique physicochemical properties of the impurities present in the drug sample. The concluded identity will unequivocally explicate the collective nature of the sub-entities in the sample as a whole. In summary, the drug profiler determines the smaller identities in order to conclude the sample identity. Drug profiling is thus a metaphysical study in many ways.

Between elements and complex structures, many intermediate building blocks are profound and not denoted explicitly. As per heroin profiling, drug chemists have been finding all possible alternatives to fill in the blanks in the comprehensive list of entities that make up each individual illicit heroin sample. With the metaphysical law of identity, it is now logical for the chemist to continue this effort to search for the underlying sum of identities since each sample and/or each part of the sample is a unique entity. In drug profiling, traditional identification/individualization means have been devoted to non-diamorphine parts of an illicit heroin sample. But current developments have also made the individualization of the diamorphine part possible. As was discussed in the previous review, many other non-diamorphine parts of an illicit heroin were chromatographically presented on a planar platform (Chiarotti *et al.*, 1991). The first rational nature of these relatively larger parts is shown as color variations and R_f values on a TLC plate under 38 sets of conditions (Rajananda *et al.*, 1985). As TLC could only identify relatively larger building blocks, more sensitive techniques such as GC and HPLC were then employed to identify even smaller entities. Under a given set of chromatographic conditions, different components having their unique physicochemical nature in an illicit heroin sample behave distinctly. Using this principle to construct a drug profile, the law of identity thus essentially guides the profiling work.

The diversity of current instrumental methods has enabled heroin profilers to disclose more building blocks of the street heroin. The identities of components such as strychnine, theophylline, noscapine and paracetamol were confirmed together with their recognized properties in the previous profiling programs (Eskes & Brown, 1975; Klemenc, 2000; Zhang, D. *et al.*, 2004). Subsequently, trace impurities began to take a vital role in coherently defining different heroin entities. Impurity profiles showing significant divergence and convergence of the identities of relatively smaller building blocks in illicit heroin samples were produced on the basis of by-products (Strömberg *et al.*, 2000; Collins *et al.*, 2006; Dufey *et al.*, 2007), trace metals (Myors *et al.*, 1998; Infante *et al.*, 1999; Bora *et al.*, 2002) and occluded solvents (Cartier *et al.*, 1997; Collins *et al.*, 2006). This trend demonstrates that the metaphysical law of identity is correct, and forensic intelligence needs to adopt this law to start off any investigation.

The analytical work seemingly progresses along a continuum which stretches from the larger compounds such as alkaloids to the smaller units of trace metals located between two extremes (Figure 3.6). To date, there have not been any published data to confirm what these two extremes are. In a broad sense, they are only recognized as a single all-identity entity and a multitude of indivisible entities respectively. Certainly, drug intelligence and drug profiling work along this continuum to obtain the identities of the entities located in the centre part between the two extremes. The sum of identities acquired along this continuum is commonly represented by their fingerprint outputs such as chromatograms and infrared spectra.

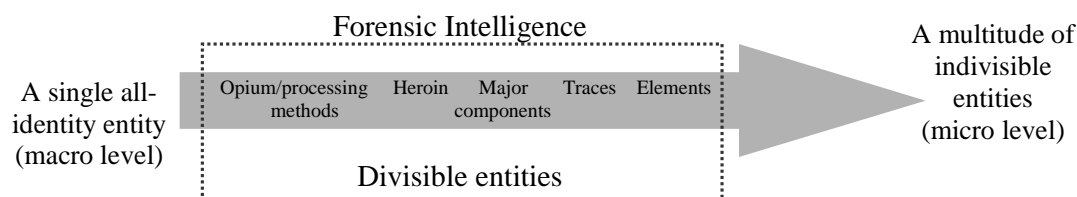


Figure 3.6: A continuum of forensic intelligence (The extremes are merely the single largest entity and the single sum of the smallest entities; an individual heroin entity based on the sum of identities is represented in the middle part of the continuum)

Other heroin profilers resorted to parts smaller than elements. For example, a mass spectral analysis displays the possible parts of a compound as fragment ions. Each fragment ion is the smaller entity of a compound. Furthermore, smaller sub-entities in terms of isotopes such as deuterium and hydrogen were also taken into consideration for advanced characterization of heroin (Hays *et al.*, 2000). Isotopic differences make each sample a more distinct entity and also provide a greater discrimination power to distinguish between samples having a similar composition. For example, IRMS was able to individualize diamorphine (e.g. isotopes of the heroin molecule) as well as non-diamorphine (e.g. diluents and contaminants) components in the illicit heroin (Casale *et al.*, 2006). Proton, electron and neutron on the other hand are probably the three monads at the most fundamental level in drug profiling. These sub-atoms do not possess windows to allow for the influx and outflow of any other entities to bring about changes to them. However, no published data have been found with reference to the manipulation of these sub-atoms in forensic intelligence.

The overall inference is that the work along the continuum in the forensic framework, undeniably, manifests the metaphysical concept that every entity is the comprehensive sum of its distinctive parts. Hence, a unique illicit heroin sample is heavily dependent on the sum of its parts. Again, this constellation consistently provides a firm foundation for forensic comparisons. Metaphysically, when two sub-samples are derived from a single homogeneous heroin entity, these will then become two

individual entities as they undergo separate causal relations at different rates. Hence, the use of the term ‘identical’ to describe these sub-samples are inappropriate because they are no longer ‘exactly the same’ in reality. This concept has already been accepted as the sixth dimension in forensic science (Inman & Rudin, 2002).

3.8.3 Causality

A change is a natural phenomenon. Some changes are observable while some go unnoticed. When an entity changes, the process is described in terms of cause and effect with respect to the properties of the entity. For example, a mass of brownish illicit heroin which exhibits similar properties in their color and texture in every part experiences changes when portions of this illicit heroin turn into black granules, resulting in two different types of heroin. The brown and black heroin samples are essentially the same entities although its properties have changed slightly. The changes are ascribed to another metaphysical force called causality. A change is an action. The action varies according to the involved entities whose natures/properties must be interacted. A change is also an effect brought about by a cause. That cause is also brought about by the previous cause.

$$\dots E_0/A_1 \rightarrow E_1/A_2 \rightarrow E_2/A_3 \rightarrow E_3/A_4 \rightarrow E_4/A_5 \dots$$

where A = action, E = effect, 1, 2, 3... = sequence of events

As forensic science aims to study the order of events, drug profiling is therefore a study of the changing effects. It also provides a retrospective view of the causes and actions acting upon a drug entity. This aspect dealing with questions responsible for a sequence of events such as ‘who’, ‘when’ and ‘how’ is usually addressed in the planning phase of intelligence (Godfray & Harris, 1971). So, the effect of an illicit heroin after undergoing changes following a sequence of interactions with all other entities is the existence of the resultant form of heroin. A heroin profile is a good

illustration to explain a variety of cause-effect relationships that have taken place within the sample. The effects are observable in terms of physical and chemical characteristics, while the causes can be predicted, either known or unknown.

In drug profiling studies, three common phenomena are expected: 1) If two different heroin samples are analyzed by an instrumental method, different profiles are obtained because these two entities have undergone two different series of cause-effect relationships. On the contrary, 2) when the same interacting nature is present in the same heroin entities, the final observable effects arising from such interactions will concur with their physical and chemical characteristics. Based on this, any part of the same heroin sample in a broad sense will show similar laboratory findings. In the strictest sense, this occurrence is impossible because the parts may undergo changes due to Kirk and Inman's principles. Therefore, 3) if identical heroin samples (referring to the parts of a single homogeneous heroin sample) are subjected to different environmental conditions, the ultimate effects will be different. Subscribing to the third phenomenon, samples from a common source will show differences in their profiles if they exist as individual entities and experience different interactions. Some of the effects may be observable but others may not be so. The observable effects can be revealed by scientific tests. Through analytical chemistry, the ultimate effects due to the changes in the drug samples are well presented by profiling. The said effects in heroin entities can be depicted in the outputs of GC (Neumann & Gloger, 1982; Allen *et al.*, 1984; Strömberg *et al.*, 2000; Zhang, D. *et al.*, 2004; Dufey *et al.*, 2007), HPLC (Huizer, 1983b) and FTIR (Ravreby, 1987). These instrumental techniques are able to illustrate whether the samples of a similar batch have experienced the same course of action if analyzed individually. The above three techniques are excellent as they offer 'library search', 'sample search' or 'output superimposition' for comparison. For instance, an FTIR result can be superimposed onto another to quickly inspect the degree

of discrepancy in their corresponding ‘fingerprints’. A significant difference would signify different cause-effect relationships, whereas a slight difference might be indicative that both samples are closely related and could be derived from a common source. In a nutshell, the profile of a heroin sample is presented as such; attributing to the sum of its nature and the interactions that the sample has undergone in its previous ‘life’.

Change is inevitably linked with time and hence the comparisons made should be in a temporal manner. Botterell’s (2004) contradiction ‘the object exists before and after a change’ will be of full validity when the chemical components in heroin samples are assessed as temporal parts (Inman & Rudin, 2002). Time is definitely a key attribute in describing changes in the property of an entity. A tree as seen by an observer for a second time is not the same tree that he saw at the first instance. The difference is that the tree has taken up more nutrients and water since the first observation. Subscribing to this metaphysical belief, a drug sample analyzed at different times will show differences. This causality is valid; hence samples analyzed at different times will tend to show two different profiles as the sum of the entities are constantly changing over a certain period of time. All entities are constantly changing however noticeable or not. A heroin sample analyzed on a particular day would show the effects as represented by the stage, E_3 . The same sample will show observable or unobservable changes if a second analysis is done on a different day. The further apart the analysis is, the more pronounced the effect is. The effect at E_{1000} is easily observable and measurable compared to that at E_4 . These changes are also the concern of heroin profiling and such phenomenon was studied by Zhang, D. *et al.* (2004) using illicit heroin (refer to Section 3.5.4 Stability). In analytical chemistry, temporal changes could be expressed in terms of variation, repeatability, reproducibility, and errors, all describing the variability of the findings arising from various factors if the samples are analyzed at different times or

under different conditions. In practice, no two samples can be analyzed simultaneously under the same conditions by the same instrument and operator. However, as the Principle of Uniformity argues that similar causes produce similar effects (Dilworth, 2006), the drug profiler understands that samples of a common source that have experienced similar cause-effect histories will show similar findings despite the minimal casual factors imparted from the analytical procedures. This understanding is equivalent to the concept of inter-batch and intra-batch variations, whereby the former is the significant cause-effect histories experienced by the batch whereas the latter is the negligible cause-effect experiences from laboratory analysis.

In reality, street heroin samples of a common source always experience a complex set of effects. The effects are exaggerated if the samples are separated in two different sets of conditions (e.g. different packages). Therefore, inter-batch variations are greater than intra-batch variations (Fraser, 2009). In this regard, inter-batch samples provide better boundaries between two entities at the batch level. It is thus important to do prior grouping before profiling begins. Despite the post-added effects, the sum of the background effects acquired before extra causes such as cutting and contamination are introduced may still be revealed by chemometrics. A common statistical technique involves the use of alkaloid ratios can obviate effects arising from cutting and instrumental errors. This technique is also applicable to the effects addressed in the following paragraph.

Analytical instruments could be a potential cause of variations. A batch of entities apparently having unnoticeable differences could show significantly measurable effects within itself when different types of interactions arising from the use of instruments during analysis are taken into account. Statistical estimation of variance is the sum of actions brought about by the operator, instrument, samples and the environment. Whichever technique is employed, the change in the measured pattern

(e.g. chromatograms, spectra, etc), due to varying conditions of storage and/or handling, is always present (Sanger *et al.*, 1979). Some of the operator's actions can be controlled because they are caused deliberately by choice (Geirsson & Losonsky, 1998). These undesirable actions can be reduced by carefully controlling the analytical settings. One of the useful ways is to adopt a harmonized method for profiling. In the harmonization study experimented by Strömberg *et al.* (2000), the heroin profiles proved to give reproducible and comparable results even though the same heroin samples were analyzed at different times in different laboratories. Although suppressing changes is impossible to achieve, minimizing the observable changes is feasible in profiling. Controlling the variables associated with the samples is tantamount to keeping down the rate of changes, so that the variation is less dependent on the time factor. This is the basis for stability studies on drug samples.

The causes and actions are inextricably intertwined with the histories or 'life experiences' of the entities. The histories of heroin entities comprising the nature of the geographical origin, ingredients used in processing, distributors in the distribution chain and all other entities with distinct properties are present in the paths the heroin samples undergo. In forensic intelligence, part of these intruding entities can be revealed as a sum of resulting effects, namely their profiles. For example, quantitative determination of alkaloids and adulterants in the illicit heroin is a scientific means of collecting and collating the cutting and contamination histories of the samples, which makes sample grouping at distribution level possible (Narayanaswani, 1985; Zhang, D. *et al.*, 2004). Other analyses focus on the histories of plant uptakes as well as contamination at the processing level. At the pre-processing level, samples having different uptake histories during the opium cultivation period will exhibit isotopic differences in heroin due to the disparity in the geographical nature. This has been demonstrated using various analytical techniques such as isotope-ratio NMR (Hays *et al.*, 2000). Other intruding

entities including adulterants (Kaa & Bent, 1986) and metal contaminants (Infante *et al.*, 1999) responsible for the observable effects in the illicit heroin have also been studied.

In conclusion, causality is a cornerstone to make profiling a meaningful study. Without such metaphysical interactions in the drug samples, forensic intelligence would not have been able to progress.

3.8.4. Necessity

Successful profilers must realize the role of necessity during data interpretation. The key questions to be considered include: why do things change? Why are there differences in the heroin profiles? Why are there substitutions of the pre-existing analytical methods? Simply, they change because of the necessity to survive. Arbitrarily, there exists a natural force to 'better' oneself to be able to adapt to the contemporary environment. The quotation from Darwin 'the survival of the fittest' can best describe this force. To illustrate, the drug profiler should consider the possibility of the use of Gates and Tschudi's (1952) synthesis of morphine in heroin production when the final product lacks the characteristics of the processed heroin which is normally derived from the natural morphine. When this occurs, the manufacturer of the illicit heroin is assumed to have adapted to the shortage of resources required for the supply of natural morphine.

The changes in the drug or the ways the manufacturers and traffickers engage to supply drugs, indeed, are the responses to necessity. Therefore, latest seized heroin is definitely different from what was observed ten years back. Besides, different processing methods indicated by new emerging occluded solvents may also suggest changes due to the necessity of cutting down the cost. Other unusual drug profiles would rather suggest adaptation to meet the global changes in opium cultivation and processing methods. This in turn urges the drug profiler to constantly work along with

the notion of necessity. The rationale why some dealers resort to the use of specific adulterants in cutting the heroin sample has a close relationship with necessity. Investigating the adulterants in street heroin is tantamount to going into the illicit drug market to identify their necessity. This was initiated by a group of researchers who studied the use of cutting agents in heroin trafficking (Eskes & Brown, 1975; Kaa & Bent, 1986; Mari, Bertol & Tosti, 1986; Klemenc, 2000). Unfortunately, not all are successful in the search of their underlying necessity. Eskes & Brown (1975), for example, could not rationalize the use of caffeine and strychnine in the street heroin encountered by them. Similarly, changes in the operation of the illicit drug markets were also studied (Natarajan & Belanger, 1998; May & Hough, 2004; Ritter, 2006; McSweeney *et al.*, 2008). So, understanding the necessity to change will somewhat help process and interpret the intelligence data more meaningfully.

However, not only have the illicit drug manufacturers/dealers responded to the necessary change, the narcotics analysts have also evolved immediately in response to the fast changing heroin, pursuant to the notion of necessity. Evolution in a modern context is loosely referred to as technology. Sjöström (2007) defended that chemistry is more of a technology than a science. The greatest evolution made by forensic analysts has been the development of sensitive analytical methods capable of high throughput as more and more samples are being analyzed over the past decade. To quote necessity again, statistical approaches were also designed to cater to the ever increasing volumes of drug cases. Changing from ‘analyzing all samples’ to ‘sampling of multi-unit drug exhibits’ using statistical approaches enables the forensic chemist to continually work on larger seizures (Clark & Clark, 1990; UNODC, 2009b). Instrumental analysis on the other hand is ever improving under the heading of ‘necessity’. Obviously, the emergence of advanced chromatographic and spectroscopic methods was the result of the need to reveal the inscape (internal landscape) of the highly complex street heroin.

3.8.5. Holons and Holarchy

Another unique metaphysical underpinning is the concept of holarchy. A holarchy is made up of holons. A system depends heavily on the smaller functional units called holons to work as a complete unit (Figure 3.7). Each holon has its unique identity and represents only a part of a general whole. A system is defined as functioning as a complete organization when all the holons at different levels are healthily relating to each another. If any of these holons, especially those at the fundamental level go defective; then the system is subject to paralysis. This is analogous to human physiology where for instance defective brain cells (the basic holons) will lead to brain necrosis which will result in the death of a person.

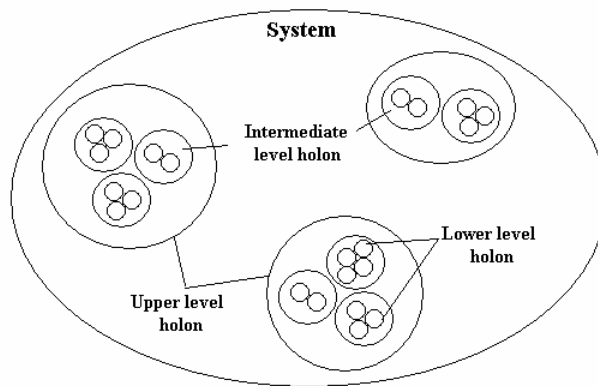


Figure 3.7: A basic concept of holarchy with the relating holons

The illicit drug market is an ideal model to describe this holarchical relation. For example, local dealers from the lower level holons work with each other to support the wholesale distributors (intermediate level holons). These wholesalers work for the upper level holons such as growers and manufacturers. The whole system works in a hierarchy and hence termed 'holarchy'. Going down the lower holons, holons smaller than this level are heroin seizures, cases, sorts, samples to name a few in more general terms. These smaller holons (e.g. heroin samples) are maintained on good terms when the drug prices in the drug market are harmonized.

In a holarchy, the lower the holon is positioned, the more important it is since all the holons above it depend on it for optimal functioning. For example, if Syndicate A which processes a type of heroin (larger holon) that is directly related to the street heroin samples (smaller holons) that are found to be less effective, low quality or too expensive than those provided by Syndicate B, then Syndicate A will be paralyzed because less bidders are interested in their product. This concept was reviewed by May and Hough (2004) in their study. To function effectively, the larger holons must ensure the smaller holons are free of defects. But the objective of the law enforcement authorities is to disrupt these smaller holons such as those at the distribution level (e.g. seizures, cases, sorts and samples) by seizing the premises with the information provided by forensic intelligence. Ideally, the whole system will be destroyed when the smaller holons (e.g. retail distributors) are no longer 'healthy'.

Forensic intelligence is guided by this concept to piece together the holarchies of the illicit drug trade. Chemical analysis is used to identify the holons (e.g. alkaloids, adulterants, metals, etc) below the sample level. On the other hand, statistical approaches such as PCA, HCA, artificial neural networks and KNN are to assign holons and establish holarchies in the heroin network using chemical profiles. From the profiling point of view, the analyst must decide on the chosen characteristics before the holons and their relationships are established. A number of such holon assignment methods were demonstrated (Myors *et al.*, 1998; Hays *et al.*, 2000; Collins *et al.*, 2006; Ratle *et al.*, 2006). In particular, Zhang, D. *et al.* (2004) utilized the smaller holons (heroin seizures) to identify larger holons (locations at distribution level) on the basis of major alkaloids. With the assigned clusters, an overview of the size of the distribution network can be quickly obtained. Each clustered level may provide useful information on how their holons work in relation to all other holons.